NASA CR-137904
WDL-TR7187A
June 1976

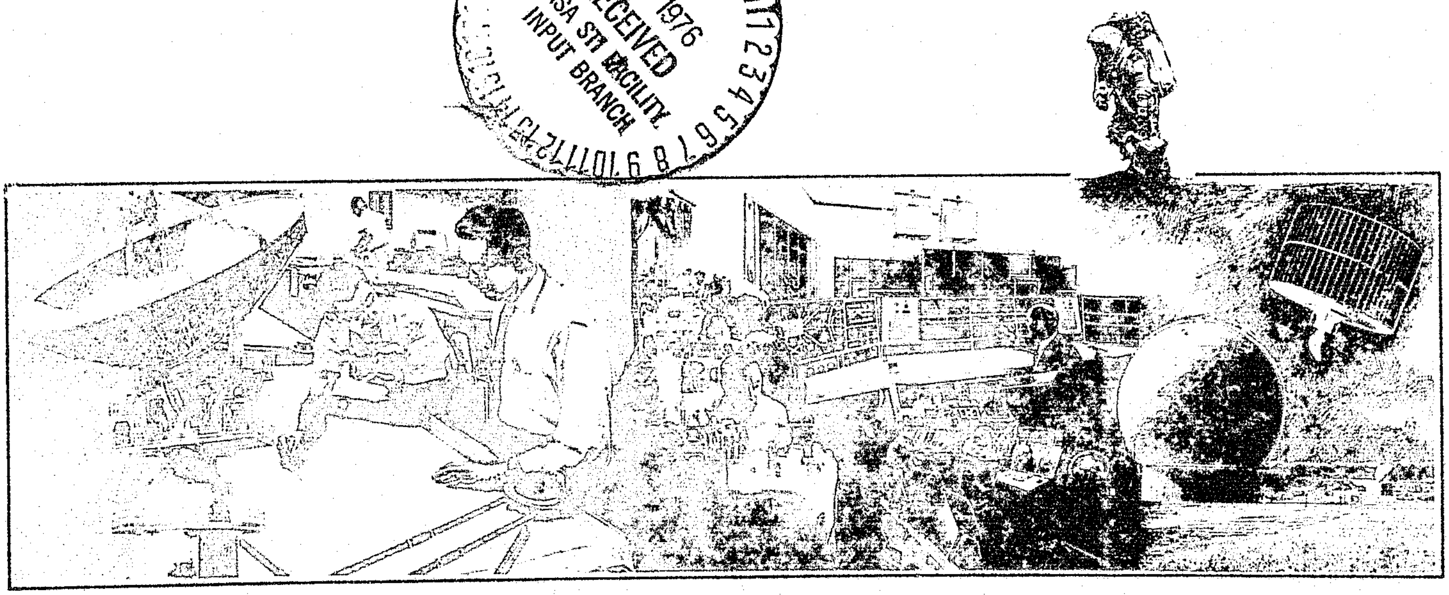
USER DATA DISSEMINATION CONCEPTS FOR EARTH RESOURCES

EXECUTIVE SUMMARY REPORT

Contract NAS2-8964

Prepared for:

NASA, AMES RESEARCH CENTER



SCI
SYSTEMS CONTROL, INC.
1801 Page Mill Road
Palo Alto, California 94304

Aeronutronic Ford
Aeronutronic Ford Corporation
Western Development Laboratories Division
3939 Fabian Way
Palo Alto, California 94303

NASA CR-137904
WDL-TR7187A
June 1976

USER DATA DISSEMINATION CONCEPTS FOR EARTH RESOURCES

EXECUTIVE SUMMARY

R. DAVIES
M. SCOTT
C. MITCHELL
A. TORBETT

Contract No. NAS 2-8964

NASA TECHNICAL MONITOR
Edgar M. Van Vleck

Prepared for
NASA AMES RESEARCH CENTER
Moffett Field, California 94035

SYSTEMS CONTROL, INC.

Aeronutronic
Aeronutronic Ford Corporation
Western Development Laboratories Division
3939 Fabian Way
Palo Alto, California 94303

TABLE OF CONTENTS

Section		Page
1.0	INTRODUCTION	1-1
2.0	OBJECTIVES	2-1
3.0	TECHNICAL APPROACH	3-1
3.1	Basic Assumptions	3-1
3.2	Study Methodology	3-2
3.2.1	Data Sources, User Requirements Prediction, and User Model	3-2
3.2.2	Network Simulation	3-7
3.2.3	Dissemination Network Alternatives	3-11
3.2.4	Evaluation Procedure and Criteria	3-12
4.0	RESULTS AND CONCLUSIONS	4-1
4.1	User Requirements	4-1
4.2	Network Configurations	4-3
4.3	Raw Data Transmission	4-6
4.4	Trunking Links	4-8
4.5	User Transmission Links	4-9
4.6	Data Preprocessing	4-11
4.7	Network Simulation	4-14
4.7.1	Computer Throughput Requirements	4-14
4.7.2	Data Transmission Alternatives	4-15
4.7.3	Impact of User Demand	4-16
4.7.4	Impact of Alaska	4-17
4.7.5	System Delay Time	4-18
4.8	Network Cost Comparisons	4-20
4.9	User Costs	4-25
4.10	Example System	4-27
4.11	New Technology Requirements	4-29
5.0	CONCLUSIONS	5-1
6.0	RECOMMENDATIONS	6-1
REFERENCES		R-1

LIST OF ILLUSTRATIONS

Figure		Page
1-1	Dissemination of Earth-Resources Data	1-1
3-1	Study Plan	3-2
3-2	Standard ERTS Orbits	3-4
3-3	User Demand Model	3-5
3-4	Timeliness Requirements Distribution vs. Number of User Requests per Coverage Cycle	3-6
3-5	Timeliness Requirements Distribution vs. Quantity Data Requested	3-7
3-6	Basic Sequence of Stochastic Events Incorporated into the Simulation	3-8
3-7	Simulation Functional Structure	3-10
3-8	Dissemination Network Alternatives	3-11
4-1	Network Configurations - Lower 48 States	4-3
4-2	Site Coverage for Raw Data Transmission - Altitude = 710 km	4-4
4-3	Network Configurations - Including Alaska	4-4
4-4	Centralized and Split Preprocessing/Distribution Networks	4-5
4-5	Site Coverage for 40-GHz Raw Data Link with 20° Min. El. - Alt. = 900 km	4-7
4-6	Trunking Links	4-9
4-7	User Dissemination Link	4-10
4-8	Data Preprocessing	4-11
4-9	Computer Throughput Requirements (User-Unique Data Transmission)	4-14
4-10	Data Transmission to User Alternatives	4-15
4-11	Comparison of Data Transmission Techniques to User	4-16
4-12	Impact of Alaska	4-18
4-13	Effect of Transponder Rate and Preprocessing Time on System Delay Time	4-19
4-14	Age of Delivered Data	4-20
4-15	Network Costs Versus Preprocessing Costs	4-24
4-16	Comparison of 30m/7-Band and 10m/12-Band Annual Costs	4-25
4-17	User Terminal	4-26
4-18	Example System	4-28
4-19	Baseline Central Facility (30m/7-Band)	4-28
4-20	Technology Requirements	4-29

LIST OF TABLES

Table		Page
1-1	Parameters of Polar Orbiters	1-3
1-2	Major Conclusion Summary	1-4
2-1	Study Objectives	2-1
3-1	Basic Assumptions	3-1
3-2	Potential Data Loads by Source	3-3
3-3	Probable Demand Volumes	3-6
3-4	Simulation Description	3-8
3-5	Simulation Input Parameters	3-9
3-6	Simulation Output Parameters	3-9
4-1	Highly Time-Dependent Applications	4-1
4-2	Lower-48-States Demand	4-2
4-3	Recommended ERS-ET Link	4-6
4-4	Required Transmission Rates, R, for Raw and Preprocessed Data Trunking	4-8
4-5	Cost Comparison - Transmission Alternatives (1.544-Mbps Transmission Link, White Sands, NM to Sioux Falls, SD)	4-8
4-6	User Transmission Links - Alternatives	4-10
4-7	Preprocessing Functions	4-11
4-8	Impact of User Demand	4-17
4-9	Summary - Network Comparisons	4-21
4-10	Cost Comparison of Lower-48-States Networks	4-22
4-11	Cost Comparison of Alaska-Plus-Lower-48-States Networks	4-22
4-12	Cost Comparison with Preprocessing at Greenbelt, Distribution at Sioux Falls	4-23
4-13	Operating Personnel for Data Dissemination Network	4-24
4-14	User Costs	4-26

SECTION 1.0

INTRODUCTION

The launch of the Earth Resources Technology Satellite (ERTS) in July, 1972, marked the beginning of a new era of data collection, processing, and dissemination for a broad spectrum of users. These users cover a broad spectrum of organizations (both public and private), missions, and technical disciplines and, therefore, present a widely diverse range of requirements for earth-resources data.

The capability of earth-resources data sensors (both satellite and airborne) will increase significantly over the next 10 years. As the capabilities for collection of this data increase, it is expected that the user requirements will also increase as new ways of utilizing the data are developed. New methods for transferring and processing the data will also be required to meet this future demand for earth-resources data.

The purpose of this study is to investigate the impact of these future capabilities and requirements on the data dissemination network, and to determine optimum ways of configuring this network. The scope of this study was limited to the continental USA (including Alaska) and to the 1985-1995 time period.

A typical data dissemination network is shown in Figure 1-1 and performs two basic functions: communications and data processing. Earth-resources data may be collected by sensors carried on several low-orbit sun-synchronous satellites (LANDSAT), one or more geostationary synchronous satellites (SEOS), aircraft, and shuttle sorties (not shown).

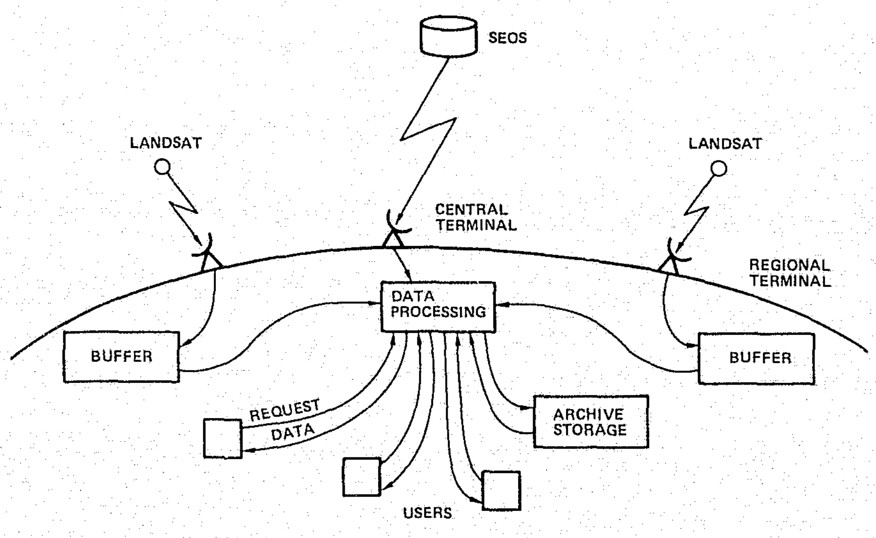


Figure 1-1. Dissemination of Earth-Resources Data

Data is transmitted from these satellites to ground terminals where it is stored in large buffer memories for transmission to the data processing center. Here, the data is indexed, corrected for radiometric and geometric distortion, and placed in long-term archive storage.

This preprocessed data is also distributed to the users, either on a regularly scheduled basis or whenever a user requests the data. Final data processing, such as classification, enhancement, identification, statistical analysis, and interpretation, may be performed either at the user, central, or area data processing facility on a time-shared basis.

Provision may also be made for dissemination of small amounts of unpreprocessed data in near-real time. The "quick-look" capability also enables a user to inspect data at the earliest possible moment and to decide which preprocessed data should be requested. The dissemination networks evaluated in this study are capable of broadcasting radiometrically and geometrically corrected data to the user community within 24 hours of its receipt from the earth-resources satellite. Therefore, the need for "quick-look" data, i.e., unpreprocessed data, should be small for these networks.

The existing data processing and dissemination system for LANDSAT-A data consists of three earth terminals located at GSFC (Greenbelt, Maryland), Goldstone, California, and Fairbanks, Alaska. The preprocessing is performed at GSFC, and the data is disseminated to the user via a distribution facility at Sioux Falls, South Dakota. These collection, preprocessing, and and dissemination functions include numerous steps which result in a system time response in the order of 30 days. Factors which contribute to this response time include the following: (a) administrative handling of data requests, (b) mailing of raw data tapes from Goldstone, California, to GSFC (Greenbelt, Maryland), (c) manual checking and editing of preprocessed data prior to release to Sioux Falls, (d) mailing of data to Sioux Falls, (e) time required to handle and process user requests at Sioux Falls, (f) time to mail data to the user.

Steps are underway to reduce this response time. A new, high-speed processor is being developed by IBM for GSFC which will geometrically correct a scene (90-m resolution/4-spectral-band LANDSAT-A image) in approximately 4 minutes. Studies are in progress considering a domestic satellite transponder for data transmission between Goldstone and GSFC, and between GSFC and Sioux Falls. With these improvements, the network response time will be reduced from 30 days to 2-4 days, plus the time required to transfer the data from Sioux Falls to the user.[1]

The next major step in the evolution of the NASA earth-resources program is the procurement of the LANDSAT-D (also known at the LANDSAT Follow-On or LFO). This satellite will generate about seven times as much raw data as LANDSAT-A (Table 1-1). A study is now in progress at NASA/GSFC to determine the best way to handle this increased data load. [2]

Looking beyond LANDSAT-D, one may hypothesize a satellite with higher resolution sensors covering more spectral bands, as shown in the third column of Table 1-1. On July 14, 1975, NASA/Ames Research Center awarded a contract to Aeronutronic Ford to consider the impact of future LANDSAT developments on the data dissemination network. The study included making a prediction of requirements for earth-resources data in the 1985-95 time frame. Optimum data dissemination networks were configured and key future technology requirements were identified. This report summarizes the results of this study. For detailed information the reader is referred to the final report [3].

Table 1-1
Parameters of Polar Orbiters

(Multispectral Scanner Only)

	LANDSAT A	LANDSAT D (TENTATIVE)	FUTURE LANDSAT
Resolution (m)	90	30	10
Number Spectral Bands	4	7	12
Raw Data Rate* (Mbps)	15	102.4	1579.2
Number Bits per Pixel	6	8	8
Number Bits per 8-min Pass**	7.2×10^{9}	4.92×10^{10}	7.58×10^{11}

* Satellite altitude = 920 km. Rate for 710 km altitude higher by factor of 1.046

** Swath width = 185 km (100 n. mi.)

A summary of the major conclusions of this study is given in Table 1-2. Additional conclusions and an elaboration of those presented here are given in Section 5.

Although this study was of necessarily limited scope, as outlined by the assumptions stated in Table 3-1, the methodology that was developed should be of use in future earth resources network studies. Suggested areas of further effort are given in Section 6.

Table 1-2

Major Conclusion Summary

- A significant potential demand exists for 1- and 2-day timeliness data.
- Timely data transmission is most economically performed by domestic communication satellites.
- The required speed of the preprocessor(s) in the dissemination network is governed by the average input data rate from the polar orbiters.
- All data from a two-polar-orbiter collection system can be preprocessed and broadcast to users within 24 hours of reception by a network incorporating a 10 min./scene preprocessor and a 6-Mbps satellite communication link (30m/7-band data) or a 120-Mbps link (10m/12-band data).
- Implementation of a LANDSAT-D-type network (30m/7-band data) is technologically feasible today.
- Implementation of a network for 10m/12-band data requires considerable advances in the state-of-the-art.
- A network with a centrally located preprocessing/distribution facility is more economical than networks with regional preprocessing/distribution facilities.

SECTION 2.0

OBJECTIVES

The objectives of this study were (see Table 2-1):

(1) To develop a flexible parametric system approach, or methodology, for evaluation of network configurations for dissemination of earth-resources data. A network-simulation computer program was to be prepared to assist in this evaluation.

(2) To configure several data dissemination networks which would satisfy predicted user requirements. These networks would serve as baselines for use in future earth-resources data management studies.

(3) To identify key technology developments required to implement these data dissemination networks. This data would be evaluated by NASA in their future planning.

Table 2-1

Study Objectives

DEVELOP THE FOLLOWING:

- A PARAMETRIC SYSTEM APPROACH FOR DATA DISSEMINATION NETWORK EVALUATION
  - INPUT FUTURE USER REQUIREMENTS
  - ADAPTABLE TO CHANGING REQUIREMENTS AND CONSTRAINTS
- A DESCRIPTION OF RECOMMENDED SYSTEMS
  - REFERENCE BASELINES FOR USE IN FUTURE DATA MANAGEMENT STUDIES
- IDENTIFICATION OF TECHNOLOGY DEVELOPMENT REQUIREMENTS

SECTION 3.0

TECHNICAL APPROACH

3.1 Basic Assumptions

To bound the problem, certain assumptions were made at the beginning of the study. These are listed in Table 3-1. While these assumptions may affect the choice of an optimum system, they will not affect the basic methodology being developed to attack the problem. For example, in a future study, areas other than continental USA could be added to the network simulation. The earth terminal locations could be changed. Data processing (including data compression) in the satellite could be simulated.

Table 3-1

Basic Assumptions

- 1985-1995 TIME FRAME
- CONTINENTAL U.S.A. (INCLUDING ALASKA) COVERAGE ONLY
- TWO SATELLITE ORBITS
  - LOW ORBIT (700-920 km), CIRCULAR, SUN-SYNCHRONOUS
  - SWATH WIDTH, 185.2 km
  - SYNCHRONOUS, GEOSTATIONARY
- FIVE POSSIBLE EARTH TERMINALS FOR ERS DATA RECEPTION
  - GREENBELT, MD
  - SIOUX FALLS, SD
  - GOLDSTONE, CA
  - FAIRBANKS, AK
  - WHITE SANDS, NM
- PREPROCESSING PRIOR TO DISSEMINATION
- DIGITAL DATA TRANSMISSION
  - 1 WORD PER PIXEL
  - 8 BITS PER WORD
- SINGLE COMMON FORMAT AND COORDINATE SYSTEM TO ALL USERS
- SYSTEM SIZED FOR MAXIMUM INPUT DATA RATE
  - CLEAR-WEATHER OPERATION
  - PEAK SEASONAL DEMAND
- IR SENSOR RESOLUTION SAME AS VISUAL
- RADIO FREQUENCY ALLOCATIONS AND FLUX DENSITIES CONFORM TO EXISTING ITU/CCIR AGREEMENTS
- 16-HOUR SHIFT, 7-DAY WEEK

The functions of the data processing system considered in this study are those associated with preprocessing and cataloging the data for ready access to the user. Radiometric and geometric correction were included. Data interpretation, classification and other user-peculiar processing were outside the scope of this study, though the impact of performing such analyses at a centralized processing facility was considered briefly.

Another basic assumption is a 16-hour-per-day, 7-day-per-week operation of all network facilities. An 8-hour shift makes inefficient use of facilities. A 24-hour shift is impractical because of the necessity for down-time for maintenance and margin against short-term shut downs.

3.2 Study Methodology

The approach used in conducting this study is shown in Figure 3-1. The study was divided into three basic tasks:

1. Predict user requirements and construct a user model for the 1985-95 time frame.
2. Predict capability and cost of data processing and communication techniques.
3. Configure, analyze, and evaluate a number of networks for processing and disseminating the earth-resources data to the user.

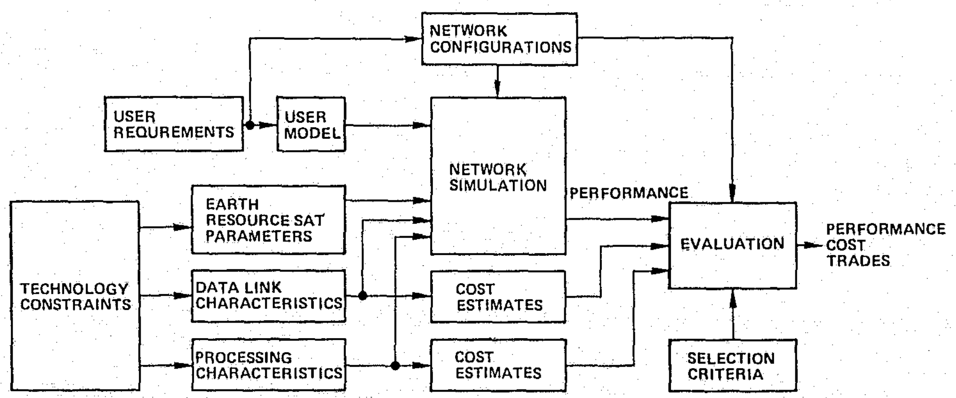


Figure 3-1. Study Plan

3.2.1 Data Sources, User Requirements Prediction, and User Model: The first task, evaluating future user requirements, consisted of reviewing previous studies and concurrently conducting personal interviews with individuals that are using or have evaluated remotely sensed data for specific applications.

Sources of data other than LANDSAT-type polar orbiters were considered (see Table 3-2). Synchronous earth-resources satellites supporting large aperture (≈ 1.5m) optics (SEOS) would generate high peak data loads during natural disasters such as tornado. Nevertheless,

these volumes would be substantially less than polar-orbiter data volume and, therefore, were not included in the user model.

Table 3-2

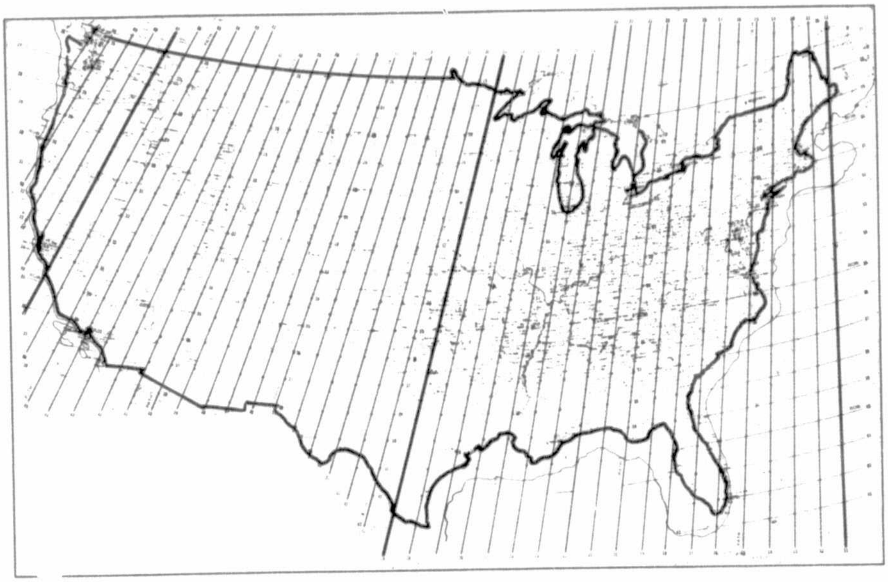
Potential Data Loads by Source

Source	Constraint	Estimated Daily Data Load bits/day
Earth Resources Shuttle Sortie	100 minutes in 7-day mission	$<2.75 \times 10^{10}$
SEOS	a. 50% time sharing with meteorology	6.35×10^{10}
	b. natural disaster - tornado	5.5×10^{9}
Aircraft	a. highly uncertain	5×10^{10} (max)
	b. natural disaster - flood	3×10^{9}
Polar Orbiters (2 satellites)	a. 7-band 30m, CONUS only	1.5×10^{11}
	b. 12-band 10m, CONUS only	2.3×10^{12}
	c. 7-band 30m, CONUS and Alaska	2.3×10^{11}
	d. 12-band 10m, CONUS and Alaska	3.5×10^{12}

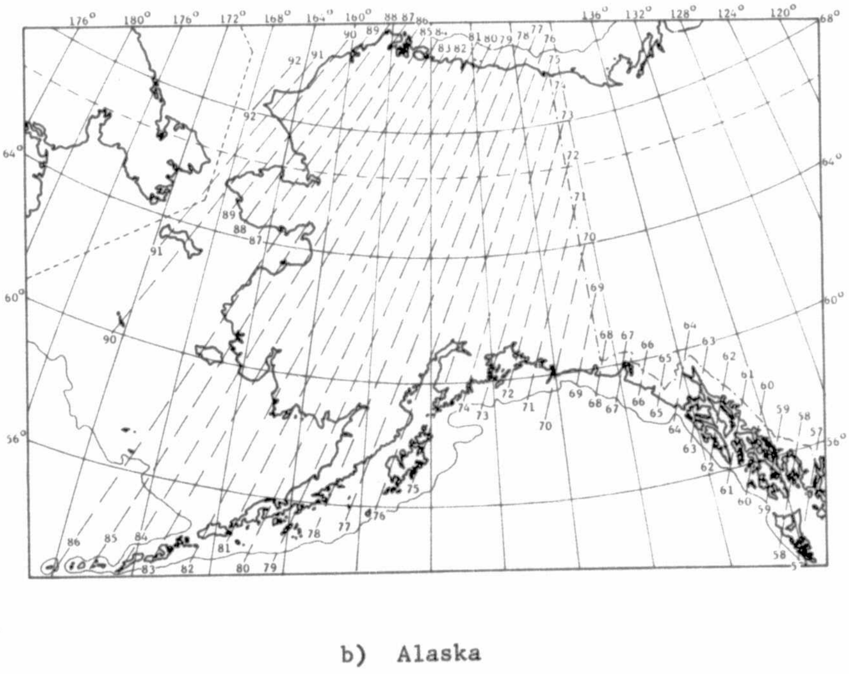
The earth-resources shuttle sortie and aircraft (U2) missions have uncertain data demand and require specialized processing facilities. Again, these data volumes are estimated to be less than those generated by the polar orbiters. These data sources also were not included in the user model.

For this study, a two-satellite polar-orbiter configuration which completely scans the continental US and Alaska in a nine-day period was postulated. Two satellite sensors were postulated: one with a 30-meter resolution covering 7 spectral bands (30m/7band), the other with a 10-meter resolution covering 12 spectral bands (10m/12 band) (see Table 1-1). The estimated daily data loads generated by these two sensor types are shown in Table 3-2.

The geographical areas of responsibility of each potential user were superimposed on satellite coverage maps (Figure 3-2) which divide the area into swaths 185 km wide. A user potential-demand model was then constructed on a swath-by-swath basis as follows: For any given swath, user X requires Y% of the total swath length (as defined in Figure 3-2) with probability Z. Figure 3-3 shows the user model for one particular swath (swath 17). For this swath, there are 24 potential users, each requiring a specified percentage of the total swath area with a given probability. The number of spectral bands desired by the user is also specified.

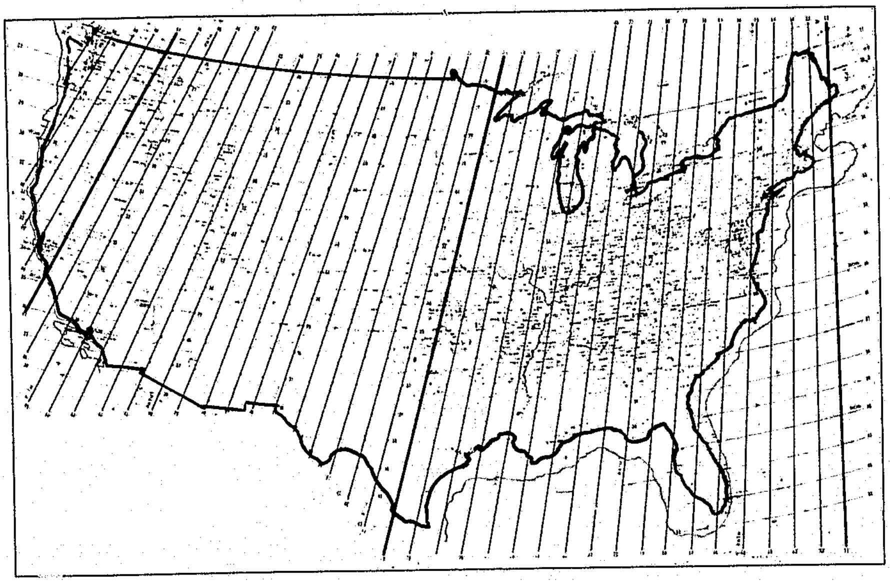


a) Lower 48 States

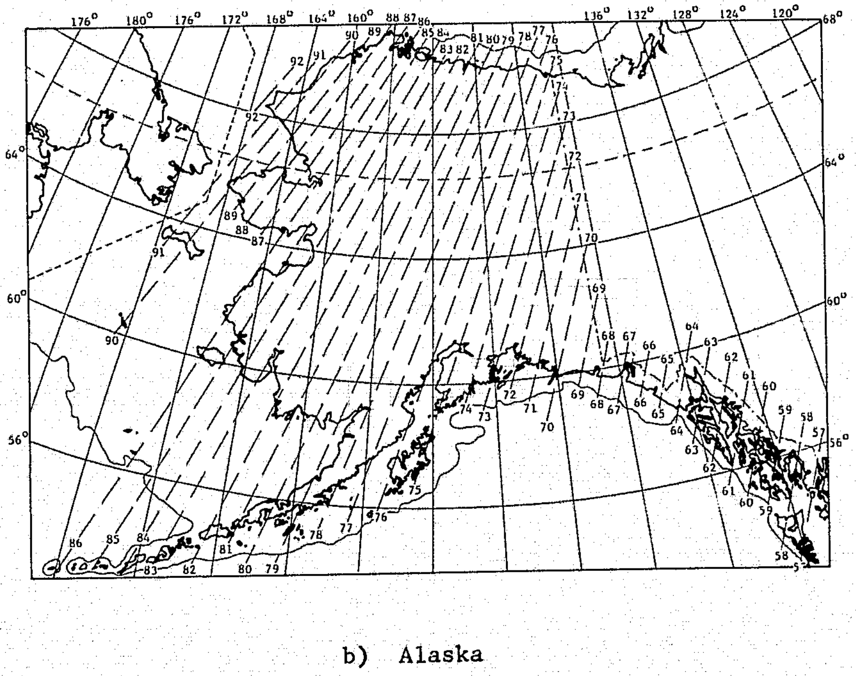


b) Alaska

Figure 3-2. Standard ERTS Orbits



a) Lower 48 States



b) Alaska

Figure 3-2. Standard ERTS Orbits

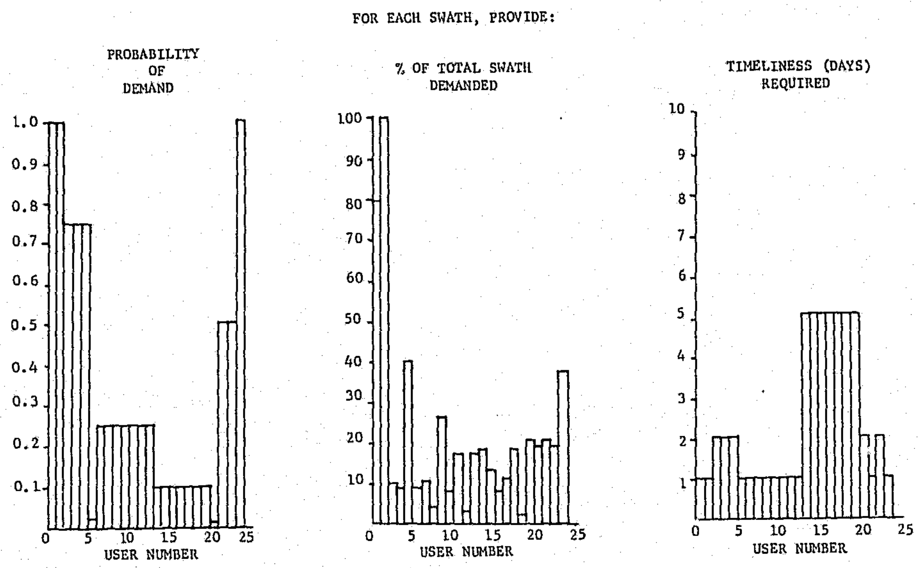


Figure 3-3. User Demand Model

Cloud cover will alter the demand for data since most users do not desire scenes with more than 20% cloud cover [4]. While the total volume of data requested may be reduced as a consequence of cloud cover, the peak or maximum demand on any given day could well be increased because of the bunching of demand on clear days. In this study, the precise effect of cloud cover was not modeled but the bunching effect was partially addressed by sizing the network for peak-demand, clear-weather operation.

To evaluate the performance of the data dissemination network, the timeliness required by each user for each swath is also incorporated in the model, as shown in Figure 3-3. "Timeliness" is defined as the time interval between satisfactory reception of raw data by an ERS readout station and reception of preprocessed data by the user. For example, referring to Figure 3-3, user number 10 requires, on swath 17, 8% of the total swath area indicated on Figure 3-2 with a probability of 25%. If user 10 does require the data at this time, he wants it within 1 day after reception by the ERS readout terminal.

Two user models were developed in this study; a "nominal" model and an "expanded" model. The expanded model contains, roughly, twice as many user requests, most of which are for small amounts of data with short (1-2 day) timeliness requirements. Table 3-3 summarizes the probable number of user requests per nine-day coverage cycle. The probable number of data bits per request is also shown for the 30m/7-band and 10m/12-band cases. Note that the probable number of bits per request decreases in the expanded user model because of the addition of user requests for small amounts of data.

Table 3-3

Probable Demand Volumes

Lower 48 States

	Probable No. of Requests/ Coverage Cycle		Probable Volume/Request/ Coverage Cycle, Gigabits	
	30/7	10/12	30/7	10/12
Nominal Case	225	225	14.3	203.8
Expanded Case	419	419	9.1	122.5

Alaska

	Probable No. of Requests/ Coverage Cycle		Probable Volume/Request/ Coverage Cycle, Gigabits	
	30/7	10/12	30/7	10/12
Nominal Case	83	83	4.9	44.4
Expanded Case	185	185	3.0	27.2

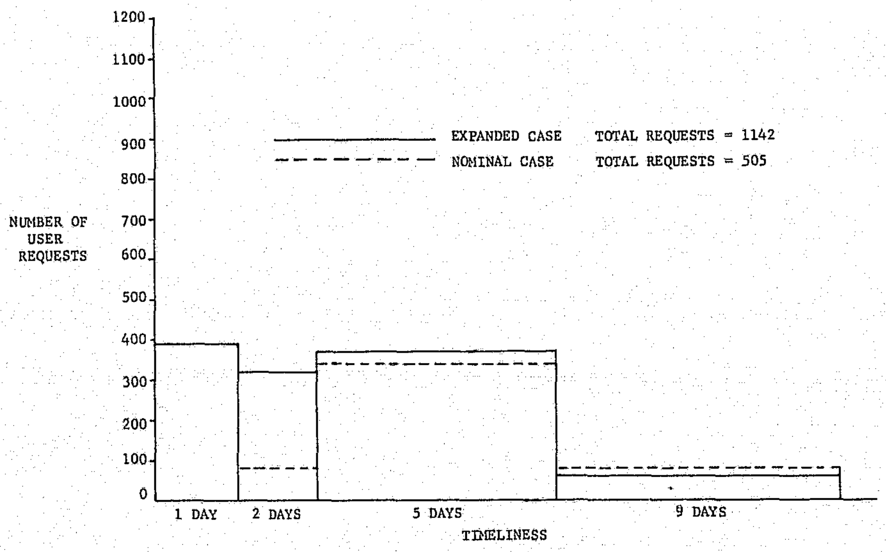


Figure 3-4. Timeliness Requirements Distribution vs. Number of User Requests per Coverage Cycle

Figure 3-4 shows the maximum number of user requests per coverage cycle and the distribution of the timeliness requirements between these requests. The difference between the nominal and expanded user models is clearly shown. Figure 3-5 shows the distribution of the size of user requests by timeliness required.

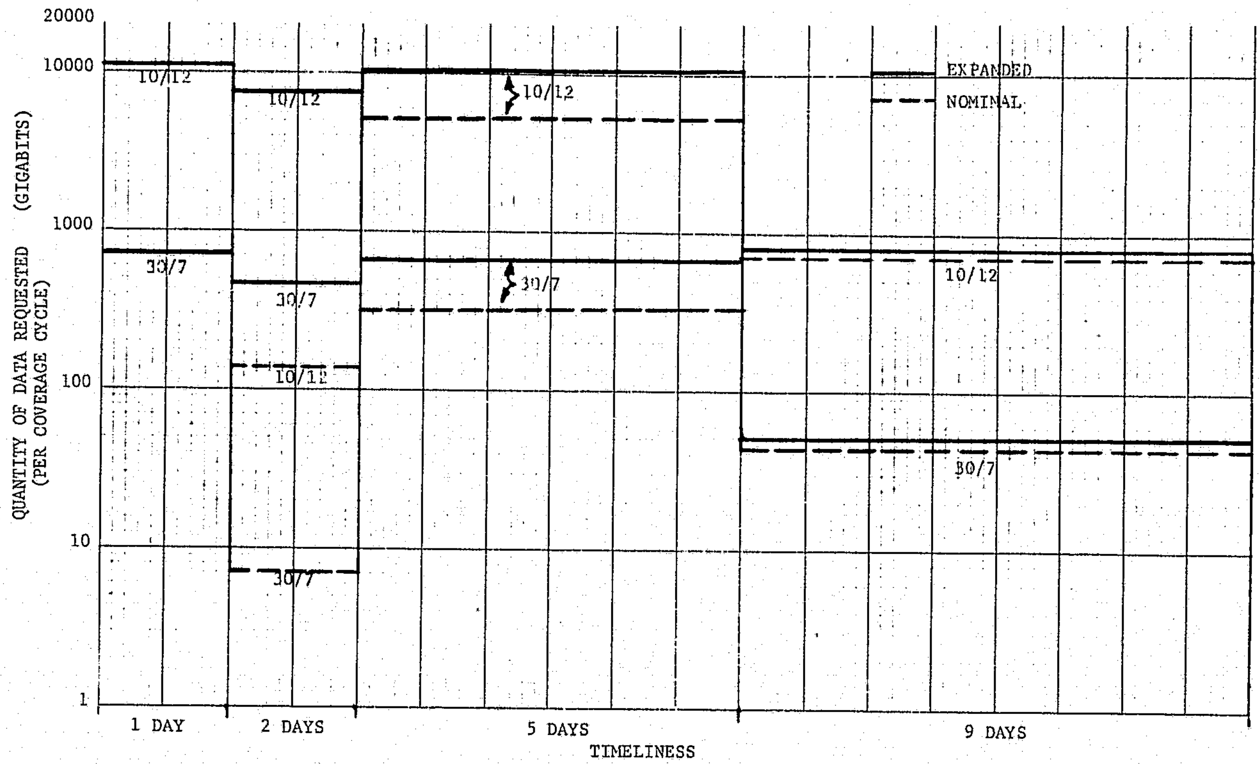


Figure 3-5. Timeliness Requirements Distribution vs. Quantity Data Requested

The purpose of having two user models was to permit an evaluation of the impact of the number of user requests and user timeliness requirements on the complexity and cost of the data dissemination network.

3.2.2 Network Simulation: To support the trade-offs and evaluations of alternative earth-resources data dissemination configurations, a versatile computer simulation was constructed to determine communication and data processing throughput, to evaluate the satisfaction of user timeliness constraints, and to assess, through simulation, the relative pros and cons for the various data distribution concepts. Key features of the simulation are listed in Table 3-4.

Figure 3-6 shows the basic sequence of stochastic events which can be incorporated into the simulation program. For this study, simulations were performed only for the sequence beginning with the time that data is actually received at the ground (readout) station.

The input parameters to the simulation program are listed in Table 3-5, and the output parameters in Table 3-6. The functional structure of the program is shown in Figure 3-7.

Table 3-4

Simulation Description

KEY FEATURES

- SIMULATE SWATHS OVER CONTINENTAL U.S.
  - USERS PER SWATH IDENTIFIED
  - USER TIMELINESS SPECIFIED
  - USER DATA VOLUME SPECIFIED
- COMMUNICATION DATA RATES CALCULATED BETWEEN SATELLITES, CENTRAL FACILITY, AND REGIONAL FACILITIES
- PREPROCESS ALGORITHM COMPUTATIONAL REQUIREMENTS CALCULATED
  - REFORMATTING
  - RADIOMETRIC CORRECTION
  - GEOMETRIC CORRECTION
  - ARCHIVING
  - STORAGE AND ROUTING
- EVENT ORIENTED SIMULATION – GESIM LANGUAGE

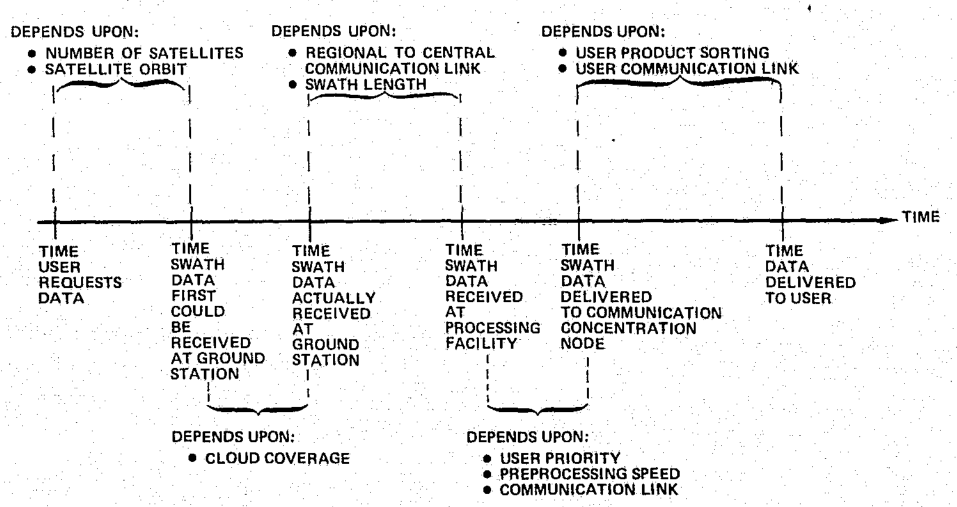


Figure 3-6. Basic Sequence of Stochastic Events Incorporated into the Simulation

Table 3-5

Simulation Input Parameters

Swath Descriptors
- Swath Number
- Satellite Look Time Window (Start and Finish Times)
- Swath Length

Satellite Descriptors
- IFOV
- Number of Bands
- Data Transmission Rate
- Number of Satellites

Computer/Algorithm Descriptors
- Computer Architecture and Computational Throughput
- Algorithm Functional Model and Instruction Count

User Descriptors
- Swath Number
- Fraction of Swath Data Required
- Timeliness Required
- Facility that Stores Data for User Dissemination

Data Distribution Descriptors
- Number of Regional Centers
- Regional (or Central) center Associated with Each Swath
- Dissemination Descriptors
  - Dedicated (or Shared) Forward Trunks
  - Dedicated (or Shared/or Broadcast) Return Trunks
  - Queueing Discipline for Trunks
    - First-Come-First-Served (FCFS)
    - Shortest-Time-To-Deadline First

Table 3-6

Simulation Output Parameters

Buffer and Processor Memory Size Requirements
- Maximum Contents
- Average Contents
- Average Utilization
- Average Resident Time
- Current Contents (at snapshot)

Data Processor Load Requirements
- Average Utilization
- Average Processing Time
- Throughput

Trunking Load Requirements
- Average Utilization
- Average Transmission Time
- Throughput

User Requirement Satisfaction
- Distribution of Data Product Age at Delivery for Various User Classes

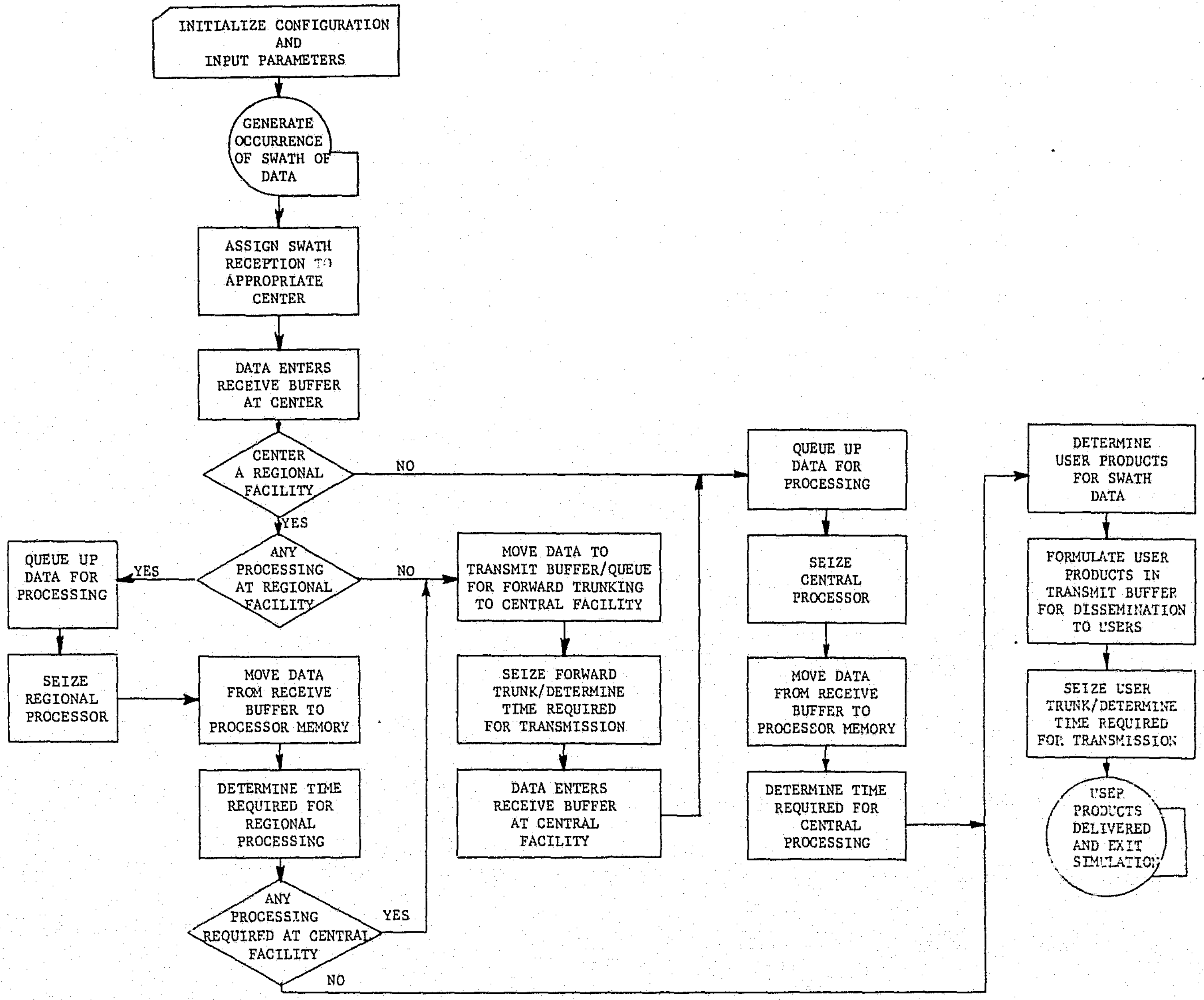


Figure 3-7. Simulation Functional Structure

The simulation program operates as follows: A swath of data is generated from a look-up table which contains the start time and the duration of each swath for each satellite. The table also contains an identifier of the readout terminal where the data is received. The number of bits per swath is generated according to the swath length, satellite sensor resolution, and number of spectral bands.

The data may flow either to a regional preprocessing center or to a central preprocessing center, depending upon the swath location and the network configuration. If the data is received at a regional facility, it may then be transmitted to a central facility via a data transmission link, called a "forward trunking" link.

The preprocessed data is distributed to the users upon user requests as generated by the user model (described in Section 3.2.1). The age of the data at the time the user receives his data is compared with his timeliness requirement to determine user satisfaction.

This simulation program, written in GESIM, has proven to be a useful tool for evaluating network performance under a variety of operating conditions. Results of these simulations are presented in Section 4.

3.2.3 Dissemination Network Alternatives: A number of network alternatives exist, as shown in Figure 3-8. The raw data from the ERS may be transmitted directly to a preprocessing facility if the ERS is in view of that facility. Otherwise, the data can be relayed via a remote readout station or via a synchronous data relay satellite (TDRS). Another alternative is to preprocess the data at each readout station as received from the ERS. Dissemination of the preprocessed data may be accomplished by common-carrier terrestrial links or by synchronous-satellite relay links directly to an earth terminal at the user facility.

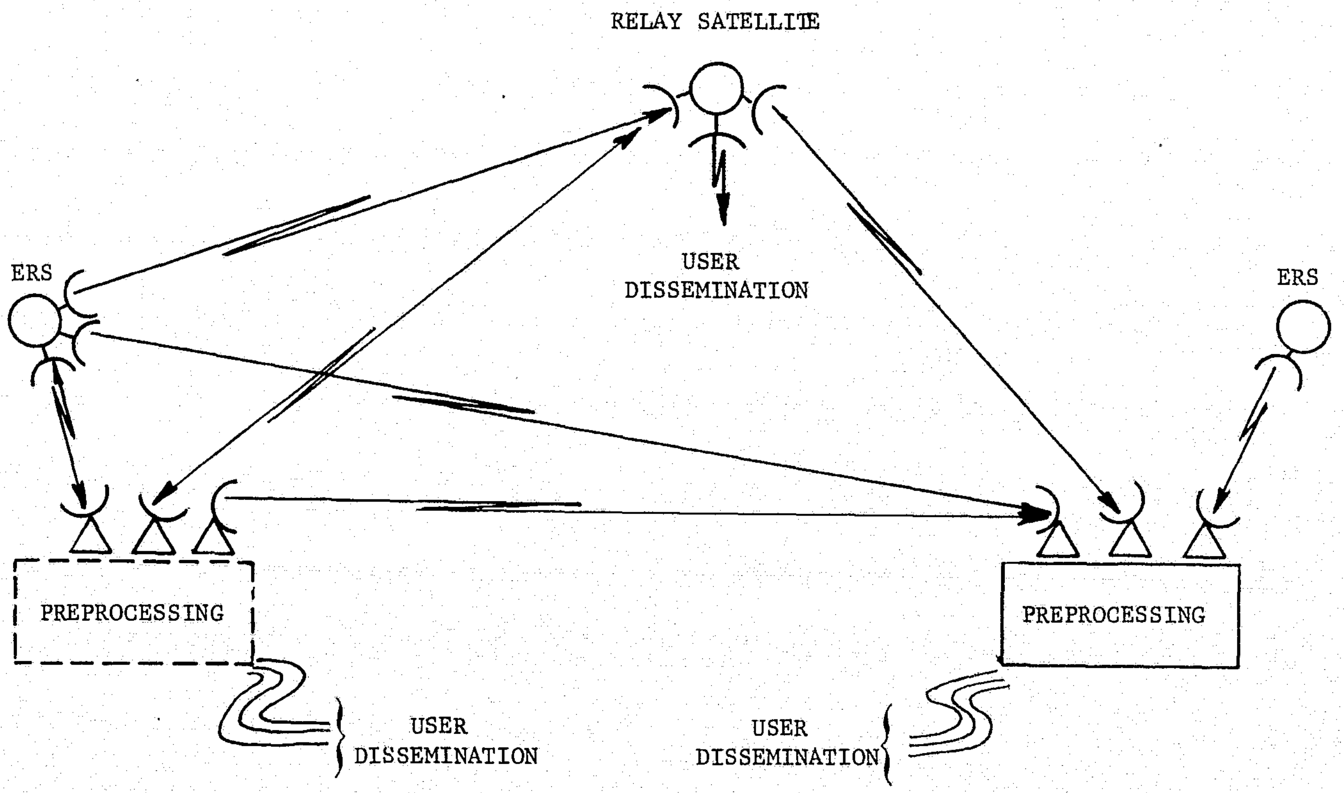


Figure 3-8. Dissemination Network Alternatives

In this study, a number of network alternatives were postulated and evaluated. The use of common-carrier terrestrial links (including common-carrier satellite links with terrestrial interconnect facilities) were investigated and eliminated due to high cost and uncertain availability. Therefore, all computer simulations were based on the use of a synchronous communication relay satellite.

3.2.4 Evaluation Procedure and Criteria: The principal criteria used in evaluating the networks were the time required to process and transfer the data to the user and the cost to implement and operate the network. A measure of dissemination network performance is the "percentage of users not satisfied" (i.e., received data later than desired). By computer simulation, minimum preprocessor speed and transmission link capacity required to satisfy all users were determined for each network configuration. The cost of implementing and operating each network was then estimated. For specific networks, the age of received data was determined as a function of preprocessor speed and link capacity. Finally, the technology risk associated with the various alternatives was assessed.

SECTION 4.0

RESULTS AND CONCLUSIONS

4.1 User Requirements

Some results of the user requirements study are summarized in Table 4-1 and show that a number of users require data in a comparatively short time period. It was found that the potential user demand with greatest impact on the user model is that shown on the last line of Table 4-1. The Department of Agriculture and the Department of the Interior have both indicated the need to obtain all of the data within 24 hours. Both agencies require a large data volume.

Table 4-1

Highly Time-Dependent Applications

Application	Turn-around Time	Potential User Organizations
Emergency Assessment	Immediate	State civil defense and planning office, numerous federal agencies, overlapping jurisdiction
Snow melt	24-48 hrs	NWS River Forecast Centers Bonneville Power Administration California Dept of Water Resources
Infestation Detection	less than 1 week (variable estimates)	State Forestry Commissions U.S. Forest Service, state and federal agricultural agencies possible
Water Management	few days	Bureau of Reclamation, Corp of Engineers
Range Management	2 - 3 days	Bureau of Land Management
Commercial Fish	6 - 12 hours	Bureau of Fisheries
Ice Monitoring	24 hours	Coast Guard, Oil Consortium,NOAA
Enforcement	variable	EPA, state agencies
Inter-agency dissemination	24 hours	USDA, USDI

Based on the user requirements study, a nominal and expanded user model was developed as described in Section 3.2.1. Table 4-2 lists the users postulated in constructing these models. Details are contained in Reference 3.

Table 4-2

Lower-48-State Demand

A. Nominal

58	FEDERAL RECEPTION CENTERS ALL DATA DELIVERED TO USDA AND USDI IN 48 HOURS
4	STATE RECEPTION CENTERS
2	REGIONAL RECEPTION CENTERS (11 STATES)
2	REGIONAL COMMISSION RECEPTION CENTERS

B. Expanded

73	FEDERAL RECEPTION CENTERS ALL DATA DELIVERED TO USDA AND USDI IN 24 HOURS
10	REGIONAL STATE RECEPTION CENTERS
14	REGIONAL COMMISSION RECEPTION CENTERS
10%	LAND AREA - PRIVATE DEMAND
3	SCENES PER PASS - UNSPECIFIED DEMAND

4.2 Network Configurations

Figures 4-1, 4-3, and 4-4 show the network configurations evaluated in this study. In Figure 4-1, configurations 1 and 2 compare regional versus central preprocessing facilities for coverage of the lower-48 states. Configuration 3 also centralizes the raw data reception function to one readout station located at Sioux Falls. This is possible provided the minimum elevation angle to the ERS is allowed to drop to 5 degrees. The 5^{o} and 10^{o} elevation contours are plotted on Figure 4-2 for an ERS satellite altitude of 710 km, and for readout stations located at Sioux Falls and Fairbanks.

Figure 4-1 shows the possible existence of area centers. An area center would receive data from the preprocessing facility and then distribute it to individual users within its jurisdiction. Such centers could reduce costs by consolidating communication and user-peculiar processing functions for a number of users, with similar requirements, located in relatively close proximity.

The area center concept is discussed further in Reference 3. All network modeling and cost analysis, however, were based on data dissemination to each user directly from the preprocessing center(s).

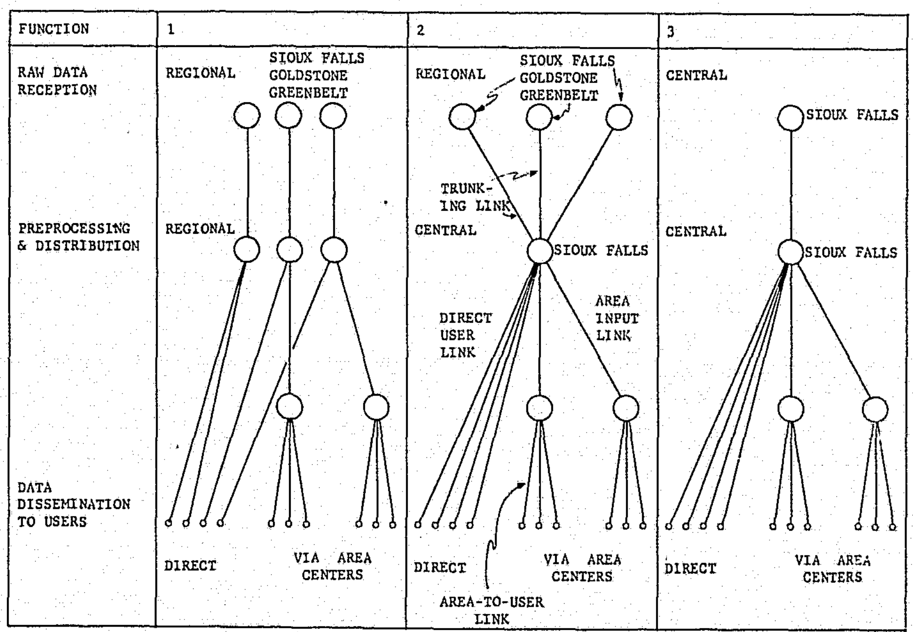


Figure 4-1. Network Configurations - Lower-48 States

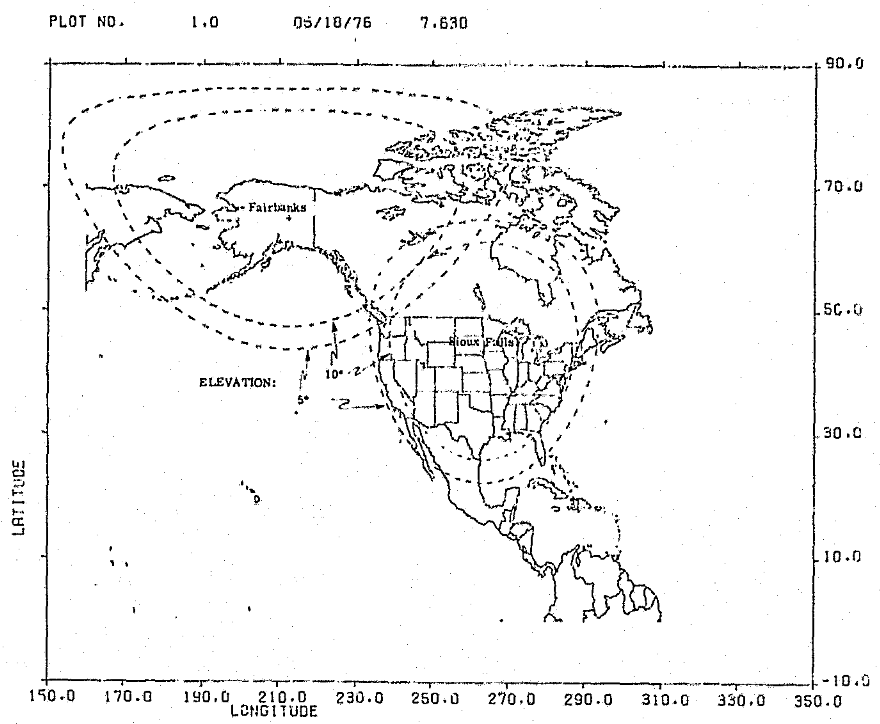


Figure 4-2. Site Coverage for Raw Data Transmission - Altitude = 710 km

In Figure 4-3, configurations 4 and 5 include Alaska in addition to the lower-48 states. Configuration 4 is configuration 3 with a separate network for Alaska. Configuration 5 centralizes all preprocessing at Sioux Falls.

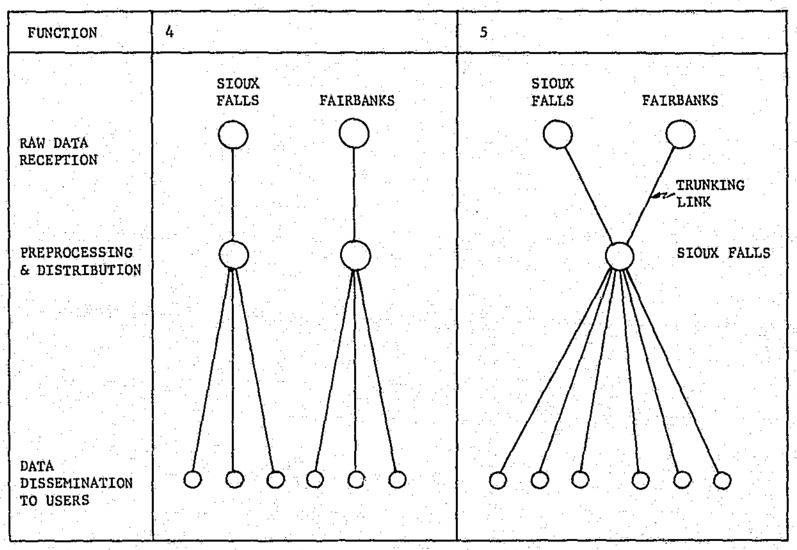


Figure 4-3. Network Configurations - Including Alaska

Figure 4-4 compares centralized configuration 5 with two other configurations currently under consideration by other groups in NASA. Configuration 6 is similar to that now in use on LANDSAT-A with the addition of a readout station at Fairbanks. Configuration 7 postulates the availability of the TDRS with preprocessing performed at Greenbelt. Another configuration (not shown) uses TDRS and performs both preprocessing and distribution functions at Sioux Falls; the only difference between this configuration and 7 is the absence of the trunk link between Greenbelt and Sioux Falls.

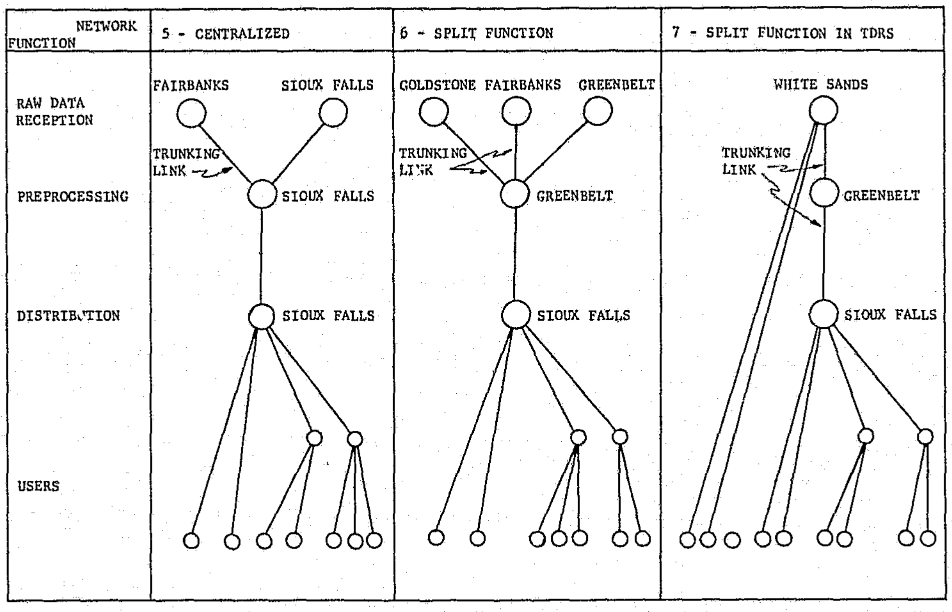


Figure 4-4. Centralized and Split Preprocessing/Distribution Networks

4.3 Raw Data Transmission

Raw (unprocessed) earth-resources data may be transmitted from the ERS to ground, either by direct link to a data readout station, or to White Sands, New Mexico via the Tracking, Data Relay Satellite (TDRS). Two raw data rates were considered, 102 Mbps and 1580 Mbps, corresponding to the 30m/7-band and 10m/12-band cases, respectively (see Table 1-1). Table 4-3 summarizes the parameters recommended for the direct ERS-to-readout station links. The first column pertains to the 30m/7-band case. The frequency band selected is 14.4-14.5 GHz. This band was selected instead of the 8.4-8.5 GHz band because of less potential interference with other services (especially the NASA Deep Space Network) and compatibility with the TDRS frequency bands, in case the ERS is designed to operate in either mode.

Table 4-3

Recommended ERS-ET Link

Resolution/Spectral Bands	30/7	10/12	
Data Rate - Mbps	102	1580	
Frequency Band - GHz	14.4-14.5	20.2-21.2	40-41
Satellite Transmitter Power - Watts	0.55	18	50
Satellite Antenna Beamwidth - Degrees	2.5	2.5	1.25
Satellite Antenna Pointing Accuracy - Degrees	0.75	0.75	0.38
Satellite Antenna Diameter - m	0.6	0.4	0.4
Earth Terminal Diameter - m	4.9	10	5
Earth Terminal Beamwidth - Degrees	0.3	0.1	0.1
Earth Terminal Noise Temperature - °K	170	300	400
Channel Bandwidth - MHz	100	1000	1000
Rain Margin (10 mm/hr) - dB	7	16	18
Minimum Elevation Angle (with Rain) - Degrees	5	5	20

The second and third columns pertain to the 10m/12-band case. To accommodate the higher data rate, it was necessary to select higher frequency bands with the required spectrum occupancy. Two bands, 20 GHz and 40 GHz, are shown in Table 4-3. The 20-GHz band is preferred, but might not be available due to projected use of this band for domestic communication satellite services. The 40-GHz band is much more susceptible to rain attenuation. To reduce the rain attenuation effect at 40-GHz, the minimum elevation angle is increased from 5 degrees to 20 degrees, as shown in the table. Figure 4-5 shows the coverage obtained from four readout stations for this case.

It is seen that the Sioux Falls location is too far north for effective coverage of southern Texas. Kansas City would be a better location.

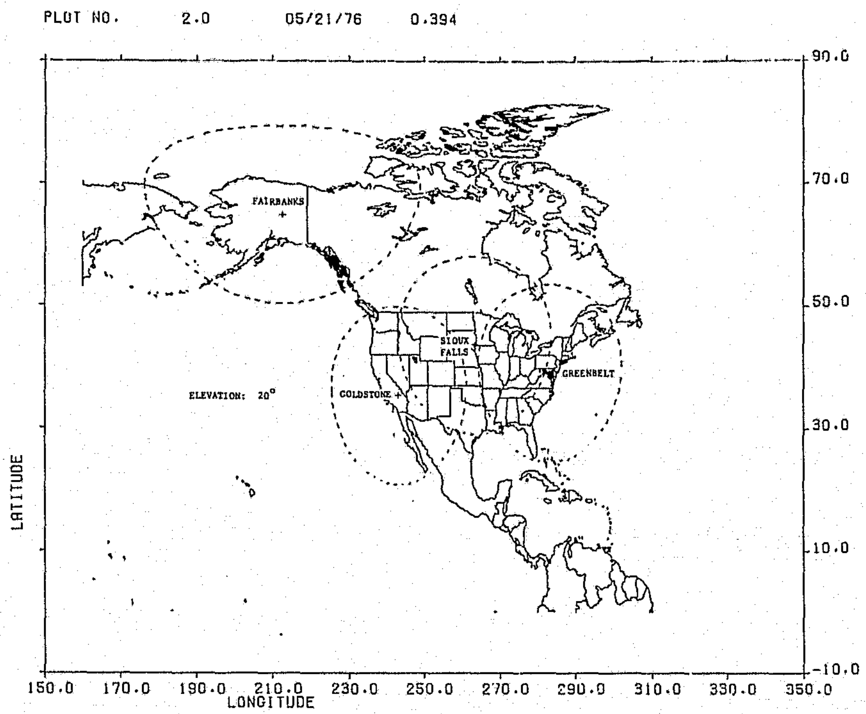


Figure 4-5. Site Coverage for 40-GHz Raw Data Link with 20° Minimum Elevation - Altitude = 900 km

The use of TDRS for ERS raw data transmission is under consideration by NASA. If extended coverage of ERS beyond the North American continent is required, then the TDRS is preferred over additional direct readout stations plus trunking links. The implementation and operational costs of the readout stations become significant, especially in foreign territory. On the other hand, the cost of the TDRS service to the ERS user has not yet been determined, making a comparative cost analysis impossible. As mentioned previously, this study considered coverage of the continental USA only.

Present plans place an upper limit of 300 Mbps on the TDRS channel capacity, limiting the ERS sensor resolution to 17.5 m (7 bands) or to 22.9 m (12 bands). Therefore, the 10m/12-band case would require development of a new wideband data relay satellite, probably operating in a higher millimeter or optical band.

4.4 Trunking Links

The trunking link is used to transfer bulk data (raw or preprocessed) from one facility to another. Figure 4-6 illustrates possible links. Table 4-4 indicates the minimum data rates (derived with no restriction on buffer storage capacity) required for the 30m/7-band and 10m/12-band cases. It is clear that, at least, a dedicated T-1 (1.544-Mbps) link is necessary for the 30m/7-band case. Table 4-5 compares the annual cost for a T-1 link implemented in one of three ways. The minimum cost technique consists of leasing a portion of a domestic communication satellite and procuring and operating earth terminals at each of the data dissemination network facilities. (Political considerations may preclude the use of this technique.) An alternative to leasing a transponder is to place a dedicated transponder on a synchronous earth-resources satellite (SEOS).

Table 4-4

Required Transmission Rates, R, for Raw and Preprocessed Data Trunking

TRANSMISSION LINK ORIGINATION POINT AND COVERAGE AREA*	TRANSMISSION LINK TERMINATION POINT	R (Mbps)	
		30/7	10/12
Goldstone, CA * Western lower 48 states	Sioux Falls, SD or Greenbelt, MD	1.89	29.1
Fairbanks, AK * Alaska	Sioux Falls, SD or Greenbelt, MD	1.39	21.4
Greenbelt, MD * Eastern lower 48 states	Sioux Falls, SD	1.59	24.5
Greenbelt or White Sands * lower 48 states and Alaska	Sioux Falls, SD or Greenbelt, MD	4.13	63.7

Table 4-5

Cost Comparison - Transmission Alternatives

(1.544-Mbps Transmission Link, White Sands, NM to Sioux Falls, SD)

TRANSMISSION ALTERNATIVE	User-Owned Terminal/ Leased-Space Segment	Satellite Common Carrier	Terrestrial Common Carrier
TRANSMISSION COST (EQUIVALENT ANNUAL COST) ($000)	$119 to $165	$225	$584

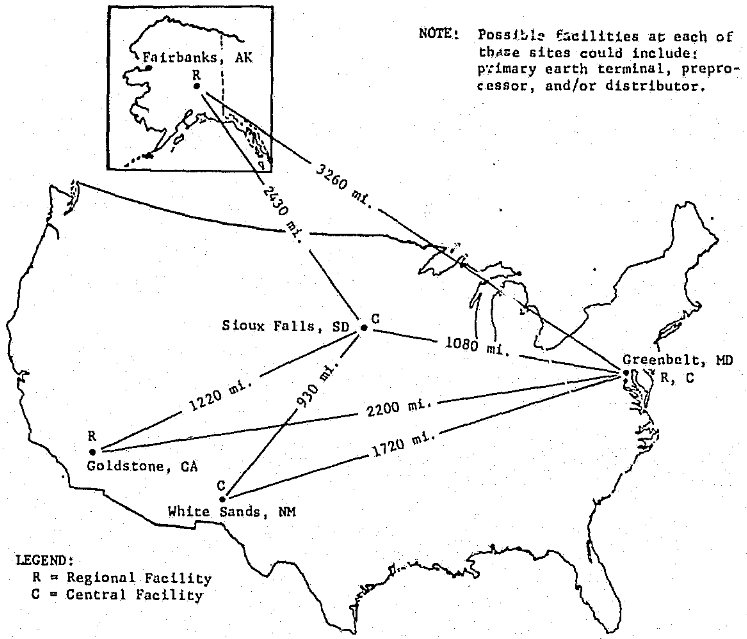


Figure 4-6. Trunking Links

4.5 User Transmission Links

A number of alternatives for transmission of data from the preprocessing facility to the user were examined. These are listed in Table 4-6. Of those that meet the user timeliness requirements, a user-owned terminal plus a leased transponder (or dedicated transponder on SEOS) was found to be most cost effective. Common-carrier systems using land lines (or conventional domestic satellites in combination with land-line facilities) do not compete, except for low data volume (less than 1 scene per request) and short distances (less than 600 miles).

Table 4-6

User Transmission Links - Alternatives

- Common Carrier (Terrestrial and/or Satellite)
  - Metered
  - Dedicated (Fixed Monthly Cost)
- User-Owned/Leased
  - Line-of-Sight Microwave*
  - User-Owned Terminal Plus Leased Transponder
  - User-Owned Terminal Plus Transponder on SEOS
  - User-Owned Terminal Plus Dedicated Synchronous Satellite*
  - User-Owned Terminal Plus Transponders on ERS*
- Mail or Special Couriers Viable Alternatives
  - Timeliness Requirement Greater than 2-5 Days
  - Function of Distance

* Alternative rejected due to high cost

The key parameters for a communication satellite data dissemination link are shown in Figure 4-7. This link operates in Ku band and uses 5-meter antennas. These terminals are small enough to be placed at a user facility (roof-top, for example). Ku band is relatively free of radio frequency interference, thus allowing the user terminals to be located in urban areas. The satellite effective isotropic radiated power is similar to that proposed by Satellite Business Systems for their domestic service [5].

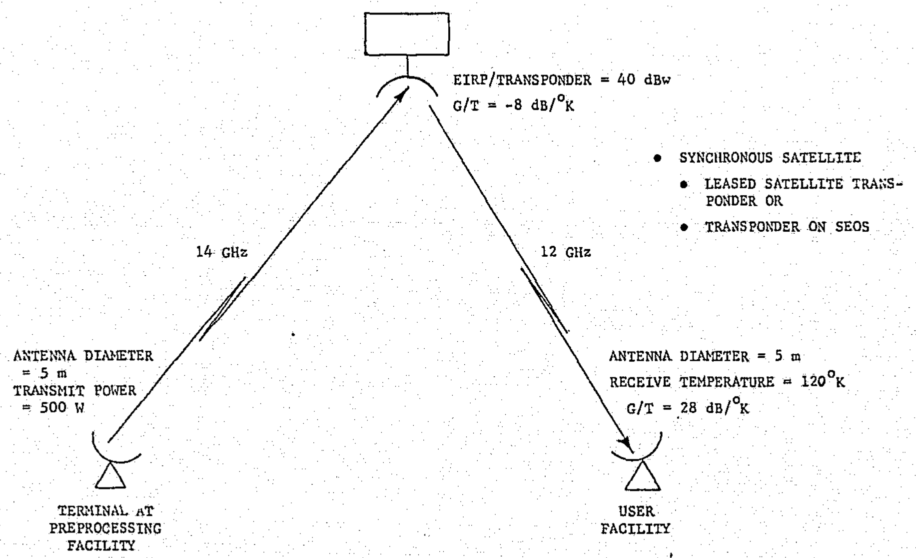


Figure 4-7. User Dissemination Link

Since satellite relays are recommended for both trunking links and user links, it is proposed that the same channel (transponder and frequency) be used for both, on a timed-shared basis. In the network simulations, the transponder capacity was sized to handle all trunking and user links in the network.

4.6 Data Preprocessing

Data preprocessing functions performed by the data dissemination network are listed in Table 4-7. A simplified functional block diagram of the data preprocessing facility is shown in Figure 4-8.

Table 4-7

Preprocessing Functions

RECORD AND PLAYBACK	CLOUD COVER ASSESSMENT
REFORMATTING	RADIOMETRIC CORRECTION
ADDRESS INSERTION	GEOMETRIC CORRECTION
CHANNEL REDUNDANCY REMOVAL	ARCHIVAL STORAGE
QUICK-LOOK DATA EXTRACTION	DATA ROUTING
CLOUD COVER EXTRACTION	

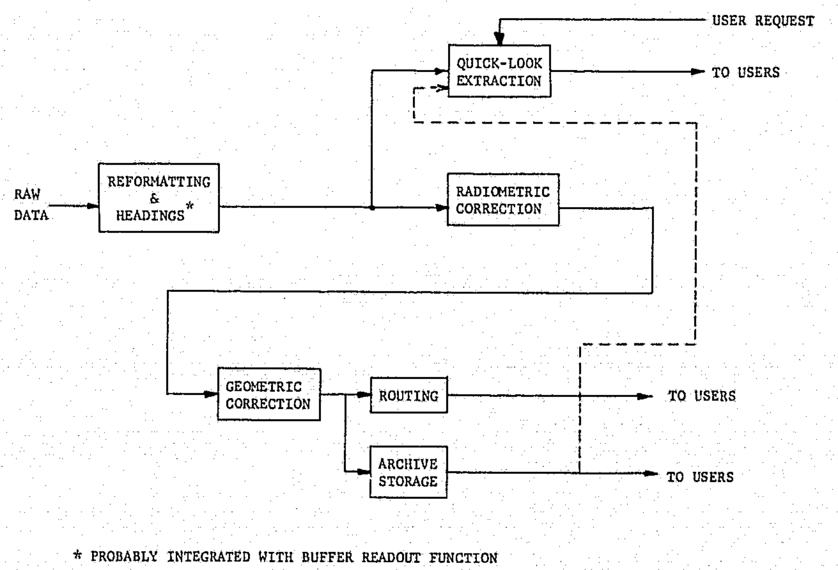


Figure 4-8. Data Preprocessing

Recording and playback are performed at each data readout station. The recording rate is at 103 or 1580 Mbps, for 30m/7-band or 10m/12-band data, respectively. Playback is at a slower rate determined by the trunking link capacity and/or the preprocessor throughput rate. The record-to-playback rate ratio is approximately 17 to 1.

Reformatting is required to rearrange the data as collected by the ERS sensors (one pixel at a time, all bands simultaneously) to a line-by-line format (one scene at a time, one band per scene). This function might be integrated with the playback function mentioned above.

Address insertion is integrated with the reformatting function. The address includes all data necessary to index or catalog each scene, such as satellite identification, spectral band, scan number, system time, and swath number.

Channel redundancy is caused by overlapping of successive cross-track scans by the ERS sensors, and is a result of the satellite altitude being too low. This redundancy is more significant at 10 meters resolution. Redundant pixels are discarded to reduce the data load on subsequent preprocessing operations.

Quick-look extraction is performed next for dissemination directly to users for preliminary evaluation. Since the networks evaluated in this study are capable of broadcasting radiometrically and geometrically corrected data to the user community within 24 hours of its receipt from the earth-resources satellites, the need for quick-look data, i.e., unpreprocessed data, will be small. Further, it is anticipated that the need for quick-look data can be satisfied by transmission of selected spectral bands and selected areas (sectors) at reduced resolution. Therefore, the impact of quick-look data on total network transmission link requirements will be small.

For example, quick-look data, consisting of 1 band at 90-meter resolution could be continuously broadcast to all users (via communication satellite). The volume of this quick-look data is only 1.6% of the full 30m/7-band data volume, and less (0.1%) relative to the 10m/12-band data volume.

Data rendered useless by cloud cover can be readily eliminated by use of cloud-cover data available from synchronous meteorological satellites. Cloud-cover assessment involves making a judgment as to whether or not a scene partially obscured by clouds is worth preprocessing and placing in archive storage. This function has been performed on an interactive basis involving human judgment (and, therefore, delays). By 1985, this assessment should become an automatic preprocessing function.

Radiometric correction is required on each pixel to compensate for variations in individual sensor detector responses. This is done by using in-flight calibration data to adjust coefficients of linear equations.

Geometric correction is the most complex and time consuming preprocessing function. Geometric distortions can arise from several factors including eastward displacement of scan lines due to

the earth's rotation, earth curvature, satellite attitude changes and altitude variation affecting the image scale. In addition, parallax distortion may arise during the comparison of two images, particularly when viewing an overlap region from adjacent passes.

Distortion due to the earth's rotation can be corrected by displacement of each line with an additional correction of the aspect ratio of each pixel. This correction, which is a function of latitude, can be performed using a priori information. Other distortions require some means of resampling the distorted input image to new locations in the corrected output image. The density values in the output image are recomputed by interpolation of some set of neighboring pixels in the input image. Various techniques have been implemented to perform this function. The first requirement is to locate the pixels in the input image to be used for interpolation. This can be done by referencing to a precision-corrected image or by comparison of 'ground control points' (GCP's) in the image to the correct GCP location from a master file. Typically, 10 GCP's are required for each scene. Improved satellite jitter performance may reduce the number of required GCP's. Alternatively scene-to-scene registration may be employed. The resulting displacements can be used to derive, as by a least-squares fit, the nearest-neighbor pixels in the input image to a given pixel in the output image. Various techniques such as a simple nearest-neighbor relocation, bi-linear interpolation or cubic convolution can then be used to calculate the density value of the corrected pixel. These techniques differ as to the number of nearest neighbors employed for each interpolation.

This study was not directed toward an evaluation of geometric correction techniques nor was the simulation based on a particular technique. The simulation of geometric correction in the network simulation is discussed in [3].

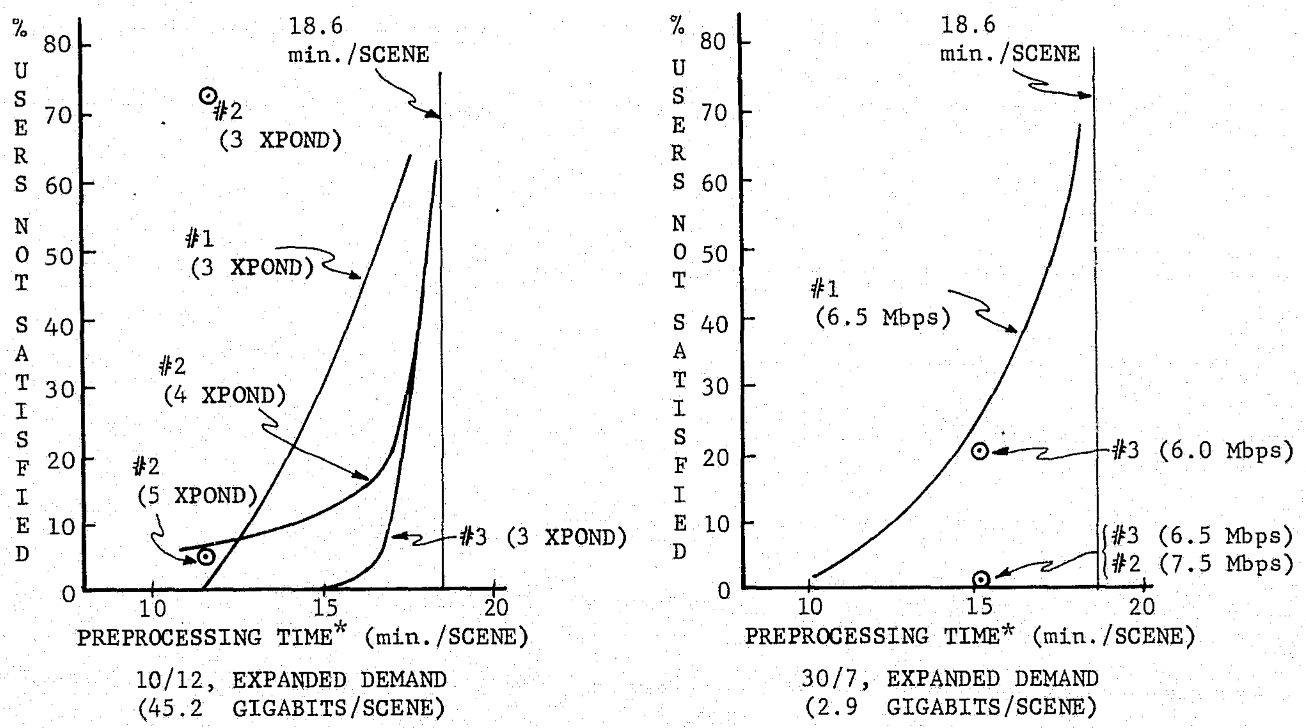
Archive storage is assumed to occur after geometric correction. As this involves 'off-line' processing, no time loss is associated with the dissemination of current data. It should be noted that the address insertion would facilitate data search for archival requests as each scan line would contain satellite source, time and latitude-longitude coordinates (nadir). Thus, record keeping would be reduced to a table identifying data on each tape. Digital logic on the output of each tape recorder could identify and select the appropriate data sets requested from archives.

Data routing consists of selecting data sets for specific users. If a broadcast mode is used to disseminate data to the user, then data routing consists, simply, of merging archival data requests with the pipeline data flow. If, however, a unique message is transmitted to each user, then the appropriate data sets must be selected and stored prior to user transmission.

4.7 Network Simulations

Over 70 simulation runs were made of the first five network configurations (Figures 4-1 and 4-2) for various combinations of the following parameters: (1) 30m/7-band vs 10m/12-band systems, (2) nominal user demand vs expanded user demand, (3) different preprocessing speeds, and (4) different transponder link capacities. Some of the results are summarized as follows:

4.7.1 Computer Throughput Requirements: The first three network configurations were simulated. Figure 4-9 shows the percentage of users not satisfied for the expanded user model as a function of the preprocessing time per scene. (A scene is defined to include all of the spectral bands.) On the average, the two-polar-orbit satellite configuration generates 51.7 scenes/day (assuming coverage of the lower-48 states only), leading to a required processing time throughput of 18.6 minutes/scene. (A 16-hour shift is assumed.)

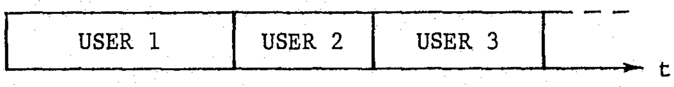


* COMBINED TIME OF 3 REGIONS IN NETWORK #1 (see Figure 4-1)

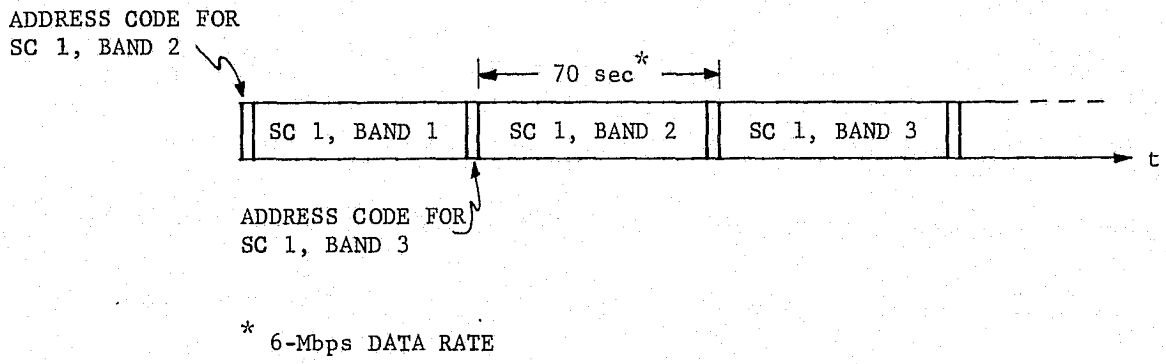
Figure 4-9. Computer Throughput Requirements
(User-Unique Data Transmission)

These results show the superiority of Network #3. Network #2 required trunking links which are not required in Networks #1 and #3. Network #2 tends to satisfy the least number of users, everything else being equal. The poorer performance of Network #2 is believed to be caused by the additional load on the transponder which must handle the trunking of raw data as well as the transmission of preprocessed data to the users.

4.7.2 Data Transmission Alternatives: Two modes of data transmission to the user were investigated: "User-unique transmission" and "broadcast transmission". User-unique transmission consists of transmitting to each user, in turn, all of the data he requested for each swath (see Figure 4-10). Users with the shortest timeliness requirement are given highest priority. (Pricing -- e.g., price vs priority -- of delivered data products was generally beyond the scope of this study.)



a. User-unique Transmission



b. Broadcast Transmission

Figure 4-10. Data Transmission to User Alternatives

This mode of data transmission proved inefficient because much of the data is transmitted more than once due tc overlapping areas requested. In the broadcast transmission mode, each scene is transmitted only once. All users wishing to receive that scene do so. As shown in Figure 4-10, an address code is transmitted prior to each scene. Each user terminal continuously monitors the signal transmitted from the communication satellite. When the address of a desired scene is received, automatic logic circuitry recognizes that address, starts up a tape recorder, and records the scene. (To provide time for tape recorder start-up, the address will actually be transmitted one scene ahead of the identified scene.)

Figure 4-11 compares the two modes of transmission. It is seen that the transponder data rate required to satisfy all users is reduced by approximately one-half by use of the broadcast transmission mode.

The sharp knees of these curves result from the fact that, in general, if the throughput capacity of the satellite transmission channel is greater than the average input data rate

(including the effect of data grouping in the user-unique transmission alternative), there will be no late deliveries of data. However, let the satellite channel capacity fall below the average input data rate, and the length of the queue to the satellite channel will, eventually, become infinite - in which case no users will be satisfied.

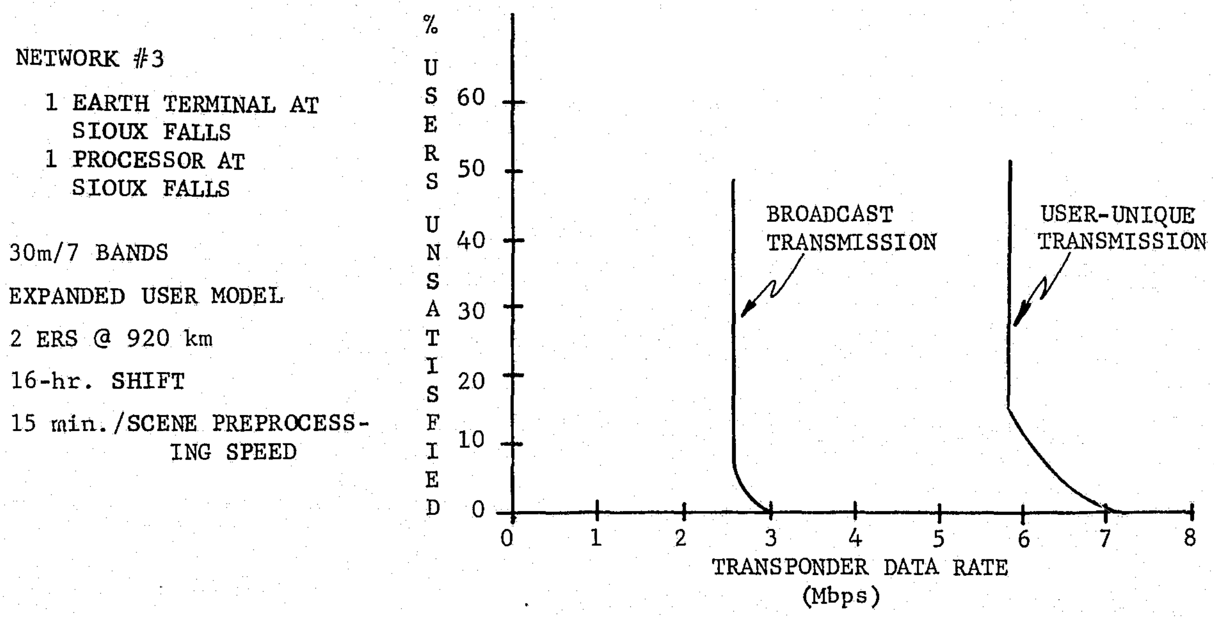


Figure 4-11. Comparison of Data Transmission Techniques to User

The more gradual knee, or broader transition region between all users satisfied and no users satisfied of the user-unique transmission curve is a result of the associated data grouping and subsequent priority queuing of the groups. (Data grouping refers to the creation of transmission groups or packets, each containing a single user's data.) Once assigned, the priority of a given group was not updated to reflect the passage of time. It, therefore, became possible for some groups to be delivered late, even though the average input data rate (including the effect of data grouping) was still less than the throughput capacity of the satellite transmission channel. Continuously updating the priority of each group would remove this possibility and make the knee of the curve as sharp as in the broadcast transmission alternative.

The broadcast mode is well suited for use with a domestic satellite, the antenna beam of which covers the entire area where users are located. If the satellite used a multiple-beam antenna with narrower beamwidths, the broadcast mode described above would be modified.

4.7.3 Impact of User Demand: Table 4-8 illustrates the effect of the expanded user demand over the nominal demand for both the 30m/7-band and 10m/12-band cases. For the 30m/7-band case, the expanded demand began to saturate the system, and 19.4% of the users did not meet their timeliness requirements. A small increase of the transponder capacity (from 6 to 7 Mbps) corrected this situation.

Table 4-8

Impact of User Demand

RES/BANDS	USER DEMAND	REQUIRED(1) NUMBER TRANSPONDERS	REQUIRED(1) TRANSPONDER DATA RATE (Mbps)	AVERAGE UTILIZATION OF TRANSPONDER (%)	NUMBER REQUESTS (9 DAYS)	DATA VOLUME REQUESTED (9 DAYS) (GIGABITS)	MEAN DELAY (HRS.)
30/7	Nominal	1	6	97.5	225	3212	20.2
	Expanded	1	6(2)	100.0	420	3808	26.7
	Expanded	1	7	87.0	420	3808	13.7
10/12	Nominal	3	40	68.5	225	45955	11.6
	Expanded	3	40	89.5	420	51365	12.7

(1) Required for 0% unsatisfied users.

(2) 6 Mbps transponder rate -- 19.4% unsatisfied users

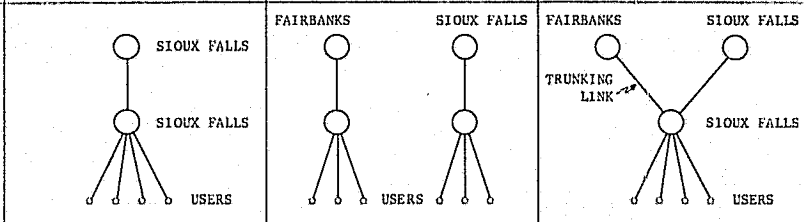
Assumptions: Lower-48 States
2 Earth Resources Satellites
Configuration 3 - Central Earth Terminal, Central Processor
User-unique Transmission
15 Minutes/Scene Preprocessing Time

The 10m/12-band system simulated contained sufficient transponder capacity to handle the expanded demand. The average utilization of the transponders increased, however, as shown.

The study showed that the network system parameters (and cost) are relatively insensitive to the choice between the two user models. Therefore, the expanded user model was used in most of the simulations.

4.7.4 Impact of Alaska: Figure 4-12 shows a comparison between Network #3 and Networks #4 and #5, where #4 and #5 include Alaska. The addition of Alaska increases the average data volume generated by approximately 50%. Preprocessing for the Alaska data can be performed separately at Fairbanks or, alternatively, at a central facility in Sioux Falls. In the latter case (Network #5), the Sioux Falls processor speed would have to be increased by 50%, and a trunking link from Fairbanks to Sioux Falls would be added. The transponder data rate shown is the total required for trunking plus user broadcast transmission. The transponder would be used on a time-shared basis between Fairbanks and Sioux Falls in Network #4 and between the trunking and user transmission links in Network #5. In the latter case, the trunking link was given priority over the user link.

30m/7BAND; EXPANDED USER DEMAND; BROADCAST MODE



	LOWER 48 - #3	LOWER 48 + ALASKA - #4		LOWER 48 + ALASKA - #5
		FAIRBANKS	SIOUX FALLS	FAIRBANKS / SIOUX FALLS
RAW DATA RECEPTION	SIOUX FALLS			
PREPROCESSING & DISTRIBUTION	SIOUX FALLS			SIOUX FALLS
	USERS	USERS		USERS
AVERAGE NUMBER REQUESTS/DAY	46.6	67.2		67.2
AVERAGE DAILY DATA VOLUME (Gbits)	151	74	151	225
PREPROCESSING TIME REQUIRED (min./SCENE)	15	30	15	10
MINIMUM TRANSPONDER TRANSMISSION RATE REQUIRED (Mbps)	[illegible]	3.9		5.2

Figure 4-12. Impact of Alaska

4.7.5 System Delay Time: Computer simulations of Network #5 were made to determine the average system delay or data age (from time of data arrival at the readout station to time data is transmitted to user). The system delay is a function of both preprocessing speed and transponder capacity. Figure 4-13 shows the relationship between these functions.

The distribution of delay of individual user requests is given in Figure 4-14. These distributions show that a majority of user requests are satisfied within nine hours. All users were satisfied within 18 hours. In these simulations, data that was broadcast to all users time shared the transponder with the trunking link from the regional facility to the central facility. Queueing discipline was first-come-first-serve with trunking given higher priority. 35 days were simulated with 16-hour/day operation.

These simulations show that, if the preprocessing speed and transponder capacity are sufficient to keep up with the data generated by the earth-resource satellites, then the system delay is fairly small. For Network #5 these limits are 5.2 Mbps for the transponder capacity and 12.5 minutes per scene for the preprocessor speed. The main objective, then, becomes one of establishing sufficient margin in the design, especially in buffer storage capacity, to insure that the system does not overload.

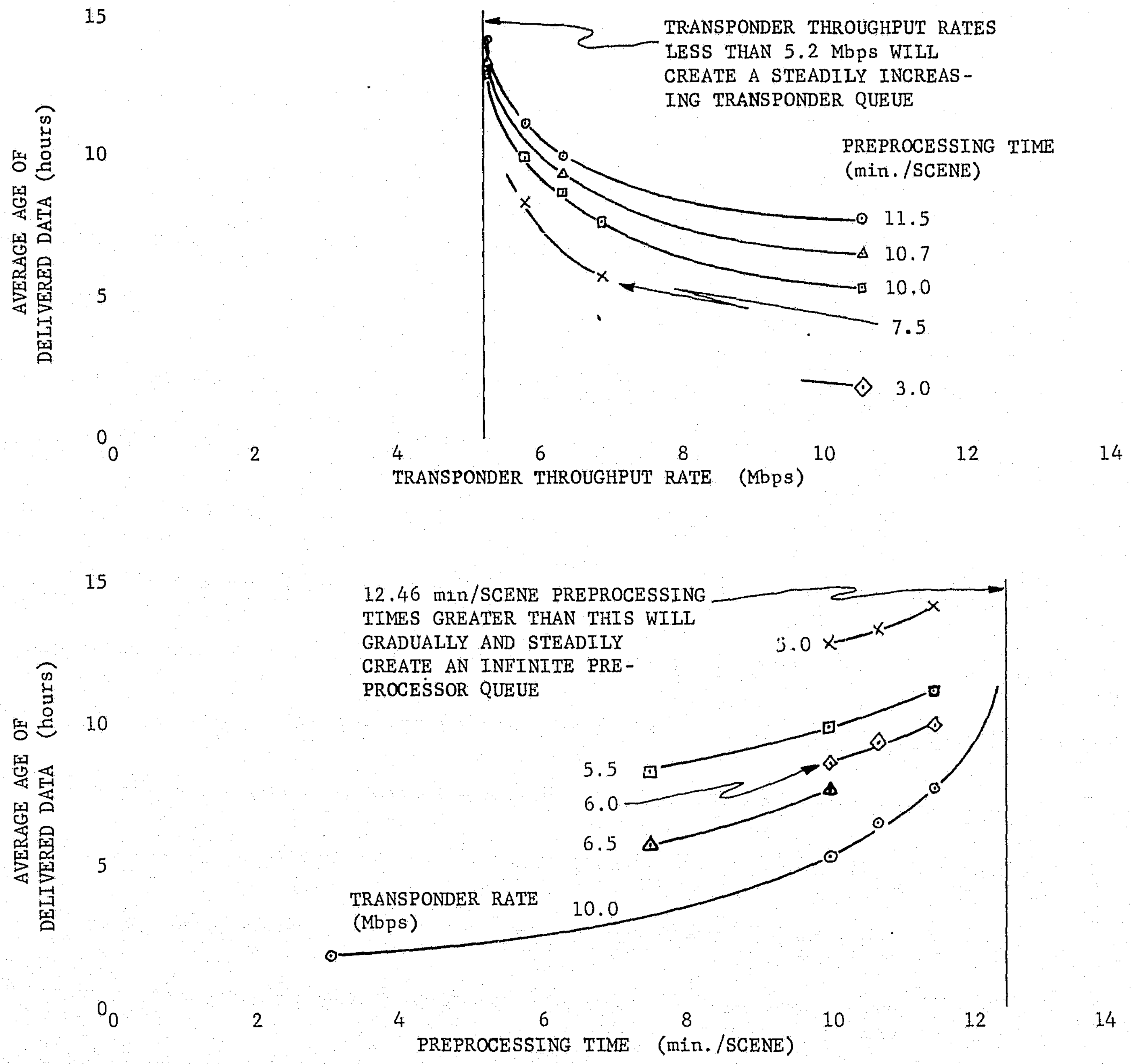


Figure 4-13. Effect of Transponder Rate and Preprocessing Time on System Delay Time

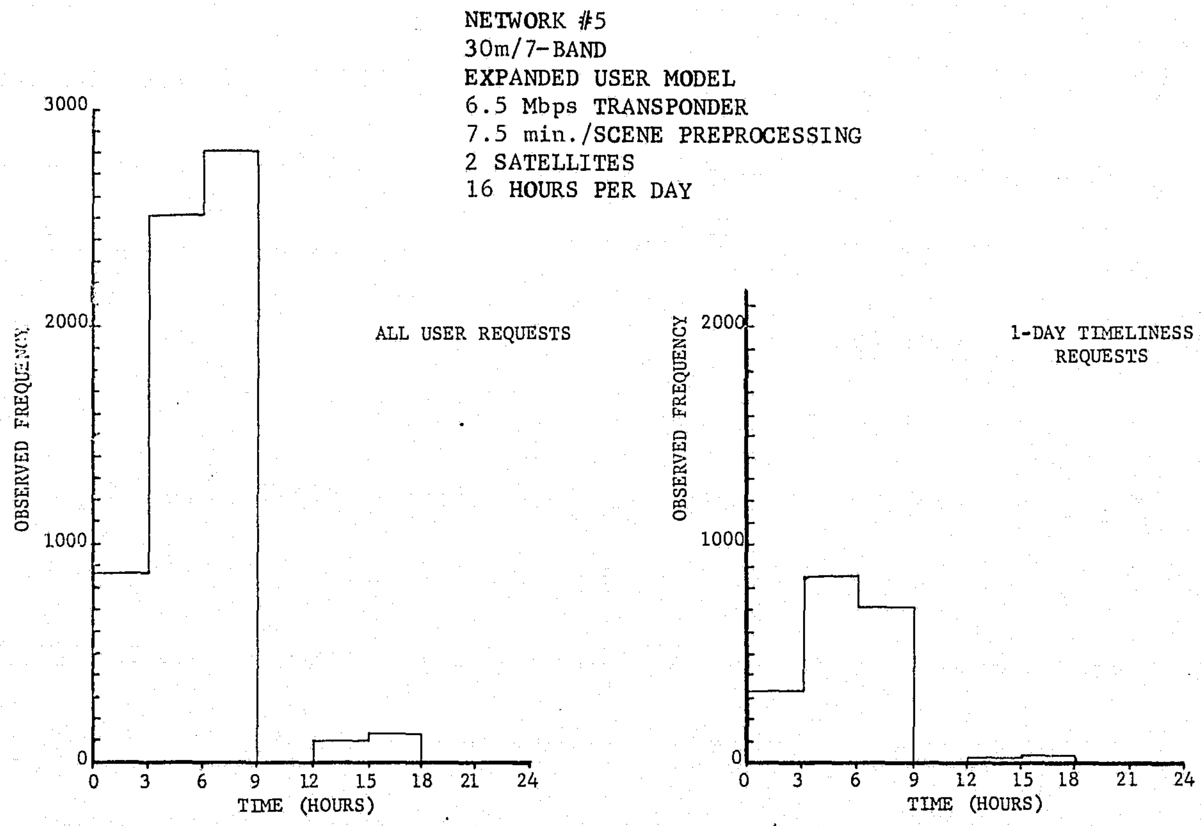


Figure 4-14. Age of Delivered Data

4.8 Network Cost Comparisons

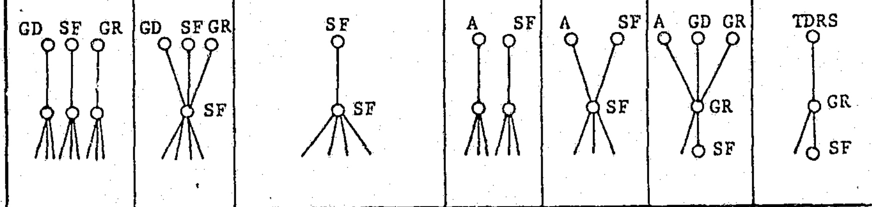
The seven network configurations described in Section 4.2 were sized to satisfy all user requirements. The 30m/7-band case and the expanded user demand model were postulated. These configurations are shown in Table 4-9. Two cases were considered for Network #3; one using user-unique transmission, the other using broadcast transmission. The annual costs were determined for each network and are shown on the last line of the table.

In comparing these costs, two facts should be noted: First, Networks #1, #2 and #3 collect data from the lower-48 states only. Second, Network #7 does not include any costs associated with the use of the TDRS (other than the cost of special digital-handling equipment at White Sands).

The following conclusions appear warranted from these results. First, the least-cost dissemination network for either the lower-48 states only or for the lower-48 states plus Alaska consists of central facilities (reception, preprocessing, distribution) to the extent possible. Second, adding Alaska to the network increases the cost of the minimum-cost network about 35%. Third, the use of TDRS in an earth-resources data-dissemination network covering only the lower-48 states would not be cost effective if its annual use charge to the network exceeded about $100K.

Table 4-9

Summary - Network Comparisons

2 ERS 30 m/7 BANDS EXPANDED DEMAND 16-HOUR SHIFT	LOWER 48				LOWER 48 + ALASKA			
	1	2	3 A	3 B	4	5	6	7
CONFIGURATION								
DISSEMINATION	UNIQUE USER			BROADCAST MODE				
TRANSPONDER DATA RATE Mbps	6.5	7.5	6.5	3.0	4	6	8	8
PREPROCESSING SPEED min/SCENE	27 42 52	15	15	15	30 15	10	10	10
TOTAL ANNUAL COST, $K/yr	4829	4043	2352	2250	4024	3046	4432	2985

NOTE: USER-OWNED EQUIPMENT AND TDRS COSTS NOT INCLUDED

Tables 4-10, 4-11 and 4-12 present the breakdown of cost data. Costs above the line are for equipment procurement and installation. Development costs and other non-recurring costs, such as preparation of documentation, are not included. Costs of redundant equipment and facilities (buildings, land) also are not included.

ERS Data Reception covers the cost of the data readout stations, including the antenna, the receiver, demodulator, buffer storage, reformatting, address insertion, and quick-look extraction. Networks #1, #2, and #6 require three readout stations, Networks #4 and #5 require two, and Network #3 requires one. Network #7 is also a single installation located at White Sands, and includes everything except the antenna and receiver. (An interface at intermediate frequency is assumed.) A single readout station costs about $900K.

Preprocessing covers all radiometric and geometric correction equipment plus auxiliary buffer storage, displays, etc. The costs are a function of preprocessing speed; being about $2.5M for a speed of 15 minutes per scene and $2.8M for a speed of 10 minutes per scene. Network #1 requires three preprocessing facilities, Network #4 requires two, and the others only one.

Archive storage covers the cost of recording/playback equipment (tape costs are not included). One set of equipment is located with each preprocessing facility.

Table 4-10
Cost Comparison of Lower-48-States Networks

2 ERS 30m/7-bands Expanded Demand 16-hour shift	ERS Reception → Preprocessing →	#1 REGIONAL REGIONAL	#2 REGIONAL CENTRAL	#3A CENTRAL CENTRAL	#3B
		USER-UNIQUE TRANSMISSION			BROADCAST
		EQUIPMENT & INITIAL INSTALLATION COSTS ($K)			
EQUIPMENT					
ERS DATA RECEPTION - THROUGH Q-L EXTRACTION		2823	2823	941	941
PREPROCESSING		3812	2550	2550	2550
POST-PROCESSING		465	155	155	155
TRUNKING (DOMSAT ET's)		186*	247**	62*	62*
TOTAL EQUIPMENT		7294	5775	3708	3708
EQUIPMENT HANDLING (10%)		729	578	371	371
INTEGRATION, INSTALLATION & TEST (20%)		1605	1270	816	816
PROFIT (10%)		963	762	489	480
TOTAL INITIAL INSTALLED COST		10591	8385	5384	5384
		ANNUAL COSTS ($K)			
Amortization (of initial installed cost: 7 yrs, 8% int.)		2034	1611	1034	1034
Maintenance (10% Total Equipment)***		733	590	375	375
Transponder (Leased)		204	230	204	102
Operation and Administration		1858	1612	739	739
TOTAL ANNUAL COST		4829	4043	2352	2250

* Transmit-only terminals. ** 3 Transmit-only and 1 Transmit-Receive Terminal
*** Includes an additional $4K for each Trunking ET (See Section 7.2.2.9)

Table 4-11
Cost Comparison of Alaska-Plus-Lower-48-States Networks

2 ERS 30m/7-bands Expanded Demand 16-hour shift Broadcast User Transmission	ERS Receiving → Preprocessing →	#4 REGIONAL REGIONAL	#5 REGIONAL CENTRAL
		EQUIPMENT AND INITIAL INSTALLATION COST ($K)	
EQUIPMENT			
ERS DATA RECEPTION - THROUGH Q-L EXTRACTION		1882	1882
PREPROCESSING		4350	2835
POST-PREPROCESSING		310	155
TRUNKING (DOMSAT ET's)		124*	185**
TOTAL EQUIPMENT		6666	5057
EQUIPMENT HANDLING (10%)		667	506
INTEGRATION, INSTALLATION & TEST (20%)		1467	1113
PROFIT (10%)		880	668
TOTAL INITIAL INSTALLED COST		9679	7344
		ANNUAL COSTS ($K)	
Amortization (of initial installed cost: 7 yrs, 8% int.)		1859	1411
Maintenance (10% Total Equipment)***		675	514
Transponder (Leased)		132	190
Operation and Administration		1358	1031
TOTAL ANNUAL COST		4024	3046

* Transmit-only terminals. ** 1 Transmit-only and 1 Transmit-Receive Terminal. ***Includes an additional $4K for each Trunking ET (See section 7.2.2.9)

Table 4-12

Cost Comparison with Preprocessing at Greenbelt, Distribution at Sioux Falls

Includes Alaska
2 ERS
30m/7-bands
Expanded Demand
16-hour shift
Broadcat User Transmission

ERS Reception → / Preprocessing →	#5 REGIONAL SIOUX FALLS	#6 REGIONAL GREENBELT	#7 TDRS GREENBELT
	EQUIPMENT AND INITIAL INSTALLATION COSTS ($K)		
EQUIPMENT			
ERS DATA RECEPTION - THROUGH Q-L EXTRACTION	1882	2823	616*
PREPROCESSING	2835	2835	2835
POST-PREPROCESSING	155	155	155
TRUNKING (DOMSAT ET's)	185**	370**	308**
TOTAL EQUIPMENT	5057	6183	3914
EQUIPMENT HANDLING (10%)	506	618	391
INTEGRATION, INSTALLATION & TEST (20%)	1118	1361	861
PROFIT (10%)	668	816	517
TOTAL INITIAL INSTALLED COST	7344	8978	5683
	ANNUAL COSTS ($K)		
Amortization (of initial installed cost: 7 yrs,8% int)	1411	1724	1092
Maintenance (10% Total Equipment)***	514	634	403
Transponder (Leased)	190	242	242
Operation and Administration	1031	1832	1248
TOTAL ANNUAL COST	3046	4432	2985

* Does not include cost of TDRS service. ** Transmit-only and Transmit-Receive Terminals
*** Includes an additional $4K for each Trunking ET (See Section 7.2.2.9)

A domestic satellite earth terminal consists of a limited-motion 5-meter antenna, 500-watt transmitter, receiver demodulator, and miscellaneous equipment. Each terminal costs $180K, installed. The installed cost of a receive-only terminal is $109K.

Installation and test costs are estimated to be 20% of the equipment costs. The total equipment costs are converted to an equivalent annual cost, assuming a 7-year equipment life and an 8% interest rate (amortized over 7 years).

Annual maintenance costs are estimated to be 10% of the annual equipment cost. The leased domestic satellite transponder cost is based on a nominal $800K per year per 40-Mbps charge.

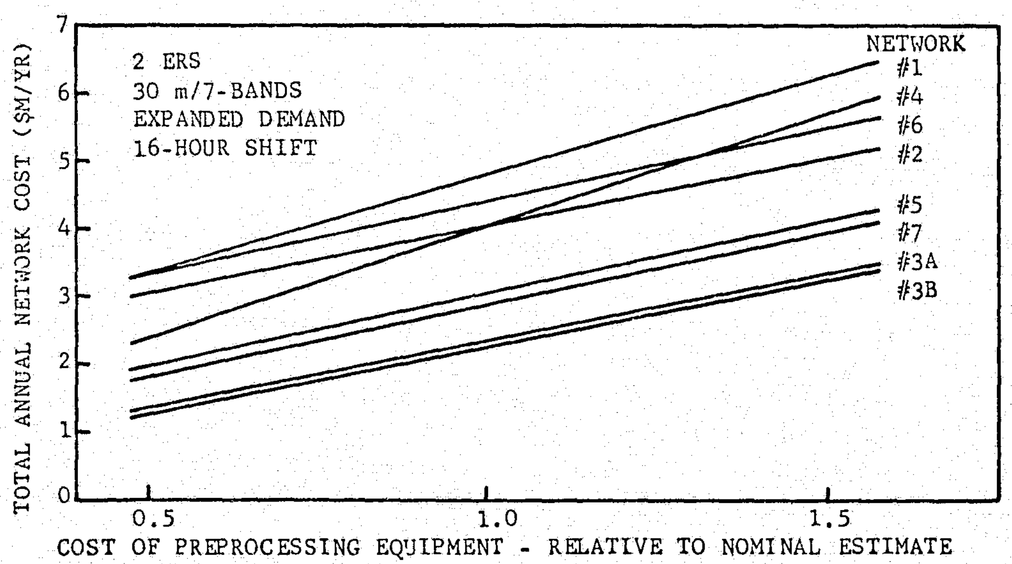
Operations and administrative costs are based on personnel assigned for each shift to perform the functions shown in Table 4-13. Two shifts (16 hours per day) seven days a week are assumed. Administrative costs are estimated at 15% of the total annual cost.

Table 4-13

Operating Personnel for Data Dissemination Network

A.	OPERATIONAL ENGINEER - acquisition, monitors BER, maintains rf equipment, operates data handling console, changes primary record tapes, maintains digital equipment.
B.	PROCESSING ENGINEER - operates and controls correction operations, maintains equipment.
C.	DATA DISSEMINATION ENGINEER - controls transmission from pipelines, archives and quick-look, changes quick-look and archive tapes.
D.	CLERK - responsible for typing, reproduction, etc., assists in maintaining archive file, retrieves and shelves archive tapes (day shift only).
E.	TECHNICIAN - performs minor trouble-shooting and repairs.

Figure 4-15 illustrates the sensitivity of total network annual cost to variations in the estimate of the preprocessing equipment cost. Rapid changes in the state-of-the-art of digital processing hardware and software make this estimate less reliable than the other cost estimates. In reading Figure 4-15, Networks #1, #2 and #3, which do not include Alaska, should be interpreted separately from the other four networks. The curves show that even a ±50% error in the preprocessing cost estimate does not change the relative order of the three lower-48-state networks (#1, #2, #3). The order of the lower-48-plus-Alaska networks (#4, #5, #6, #7) is changed slightly only if the nominal equipment cost estimate proves to be low. In this case, Network #4 would become slightly more costly than Network #6. Networks #5 and #7, however, continue to be the least-cost choices regardless of the cost of the preprocessing equipment. It is interesting to note that the cost difference between Networks #4 and #5 decreases with decreasing preprocessing costs. A crossover would occur when the dual processing facilities of Network #4 become less costly than the trunking link of Network #5.



NOTE: Networks #1, #2, #3 cover lower-48 states only, others include Alaska.

Figure 4-15. Network Costs Vs Preprocessing Costs

Detailed cost estimates for the 10m/12-band case were not attempted because of the rather large extrapolations in the state-of-the-art required (see Section 4.11). Figure 4-16 presents an approximate extrapolation from the cost figures described above for Networks #1 through #5. The main difference between the two cases is the cost of data transmission which is expected to increase more rapidly than the cost of preprocessing, thus magnifying the advantage of the broadcast mode over the unique-user transmission mode (Network #3B vs #3A). Further details may be found in the Final Report [3]. No development costs were included in this comparison.

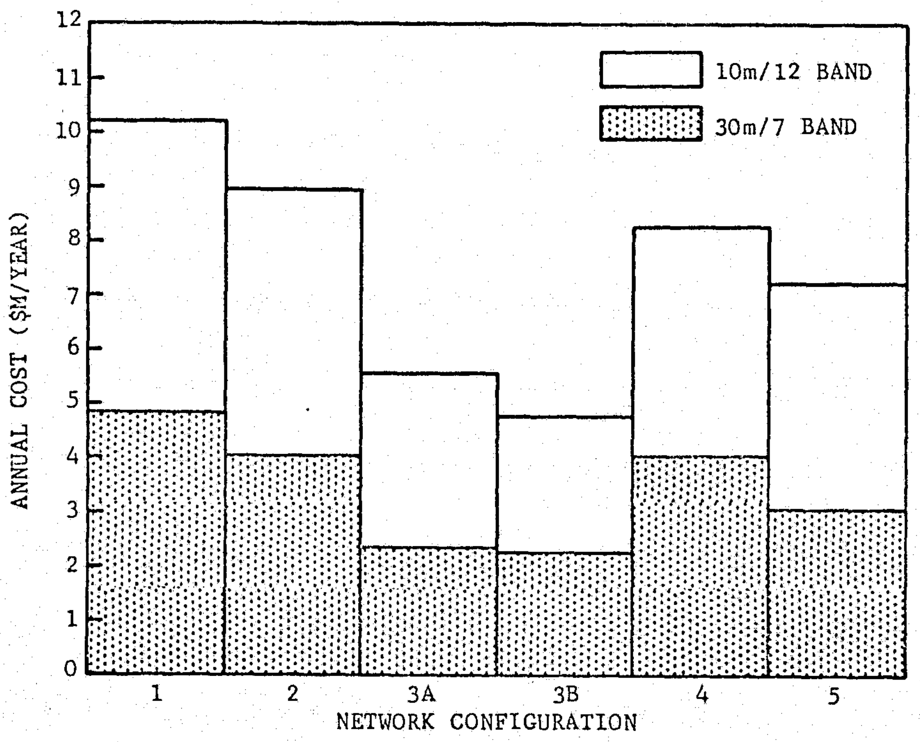
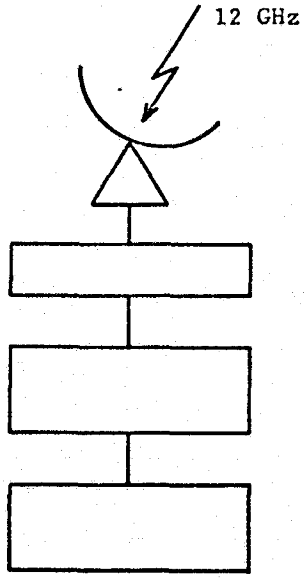


Figure 4-16. Comparison of 30m/7-Band and 10m/12-Band Annual Costs

4.9 User Costs

The network costs derived in the previous section did not include the cost of the user terminal required to receive the data from the communication satellite. To estimate an annual cost per user, it is assumed that the network costs are divided evenly among all users. While this is not likely to be the case in actual practice, the result should indicate the cost to an average user.

Each user owns a small receive-only terminal operating at 12 GHz which consists of the equipment shown in Figure 4-17. This figure also shows the breakdown of equipment costs which total $75K. This cost is used in deriving a total annual user cost shown in Table 4-14.



	COST - $K
5 m DIAMETER LIMITED MOTION ANTENNA	12
LOW NOISE PREAMP (120°K)	18
DOWN CONVERTER AND DIGITAL RECEIVER (DEMOD)	20
ADDRESS AND DATA EXTRACTION	20
MISCELLANEOUS	5
TOTAL EQUIPMENT COST	75 K

Figure 4-17. User Terminal

Table 4-14

User Costs

$$\text{AVERAGE ANNUAL COST} = \left(\frac{\text{ANNUAL NETWORK COST}}{n}\right) + \left(\begin{array}{c}\text{INITIAL INSTALLED}\\ \text{USER TERMINAL COST}\end{array}\right)^{*} \times (1/5.2)^{**} + (2.5K + 0.10 \times \$75K)^{***}$$

$$= 3046K/n + 109K \times Q(n)^{****} \times (1/5.2) + 10K$$

$$= 3046K/n + 21K \times Q(n) + \$10K$$

=

n	25	50	100	200
AVG. AC	145K	$83K	$51K	$35K

n = Number of Users
No Operator Required for User Terminal Operation
No Facility Costs

* Equipment Cost x Quantity Procurement Factor + Equipment Handling Cost (10%) + Installation, Alignment, & Test (20%) + Profit (10%)
= EC x Q(n) x 1.1 x 1.20 x 1.1 (Non-Tracking Antenna, Single-Rate Demodulator)

** Amortization of Capital (7 years, 8%)

*** Annual Maintenance (10% of Equipment Cost + 2.5K)

**** See Figure 7-17 for a definition of the quantity procurement factor, Q(n)

The annual cost for Network #5 (from Table 4-11) is divided equally among n users. For example, for n = 100, each user pays $30K per year as his share of the network costs plus $21K per year for his terminal costs. Assuming a demand of 500 scenes per year for the average user, the cost per scene is $102.

The above analysis gives a rough idea of what an automated high-speed data-dissemination network would cost to a user. Actual user cost per scene could vary significantly from the figure derived above, depending upon the degree to which the earth-resources program is subsidized by the government, the number of users sharing the costs, and the number of scenes required. Furthermore, user processing (classification, analysis, display) costs must be added to obtain the total cost.

The current (1975) user cost for digital data on computer-compatible tapes (CCT's) from the EROS data center in Sioux Falls is approximately $200 per scene (one tape) [6]. Two factors should be noted in connection with this cost. First, the ratio of the volume of data in a planned 30m/7-band scene from LANDSAT D to that of a 90m/4-band LANDSAT-A scene is approximately 15. In practical terms, this would require 15 CCT's/scene rather than 1 (and perhaps entail a similar 15-fold increase in cost) if the present data density of 1600 bpi were maintained. Second, in contrast to the estimated $102-per-scene cost developed above, the dollar value of current EROS products covers the cost of reproduction only and does not include any of the following: total EROS center costs, NASA operating costs associated with data reception, costs of data transfer from reception sites to the central data center, the National Data Processing Facility (NDPF) costs, or correctional processing costs including NDPF operations. In addition, the costs of data transfer from the Sioux Falls data center to the user are not included.

4.10 Example System

Figure 4-18 illustrates the implementation of network configuration 5 (see Figure 4-2) for the 30m/7-band case. The ERS raw data link parameters are given in the first column of Table 4-3. The domestic communication satellite link parameters are given in Figure 4-7. As mentioned previously, the satellite link utilizes a single frequency channel which is time-shared between the Fairbands-to-Sioux Falls trunking link and the user broadcast transmission link. The trunking link has first priority.

The central facility at Sioux Falls is implemented according to the block diagram shown in Figure 4-19. (The trunking link interface is omitted for simplicity.) This implementation is described in more detail in the Final Report [3].

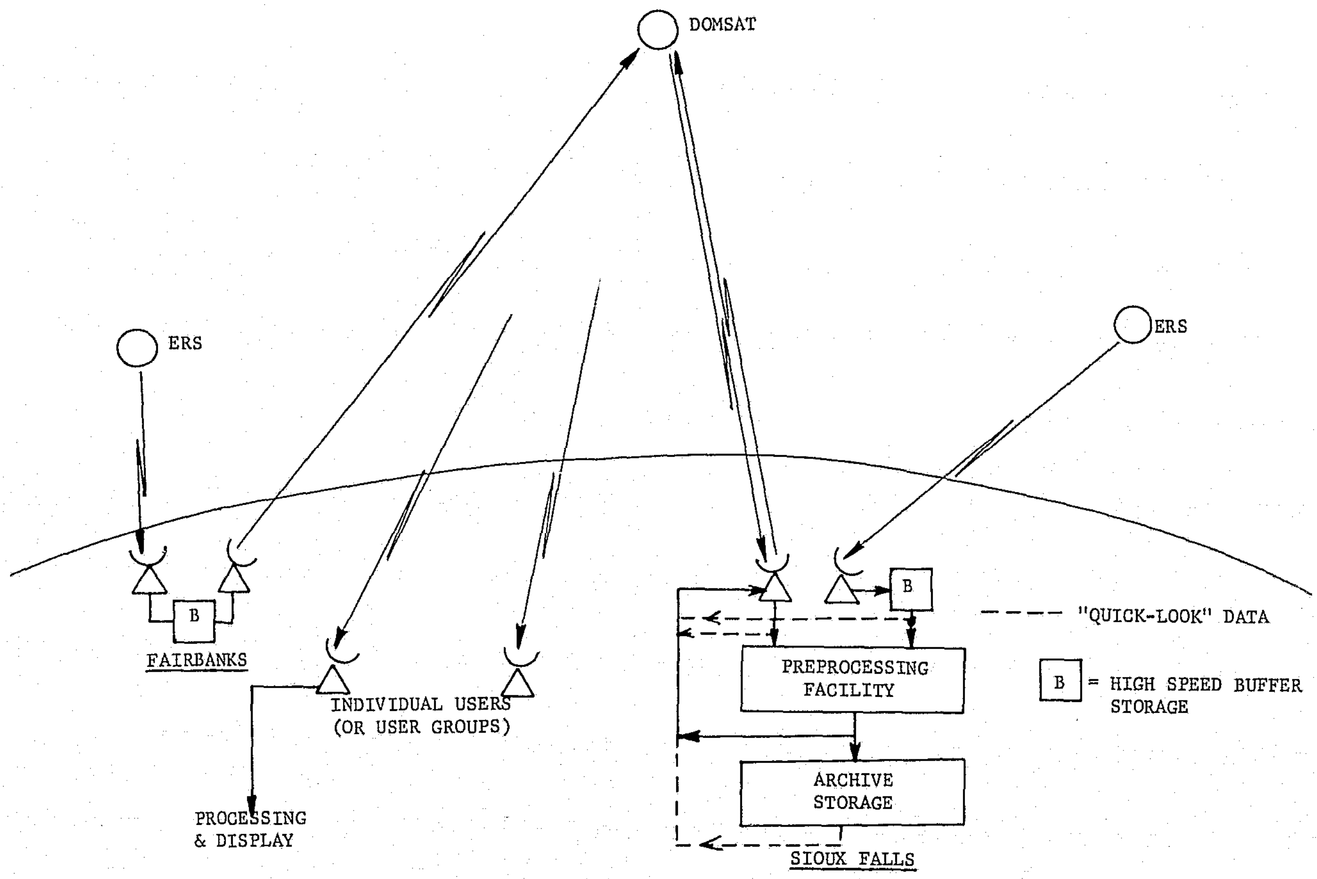


Figure 4-18. Example System

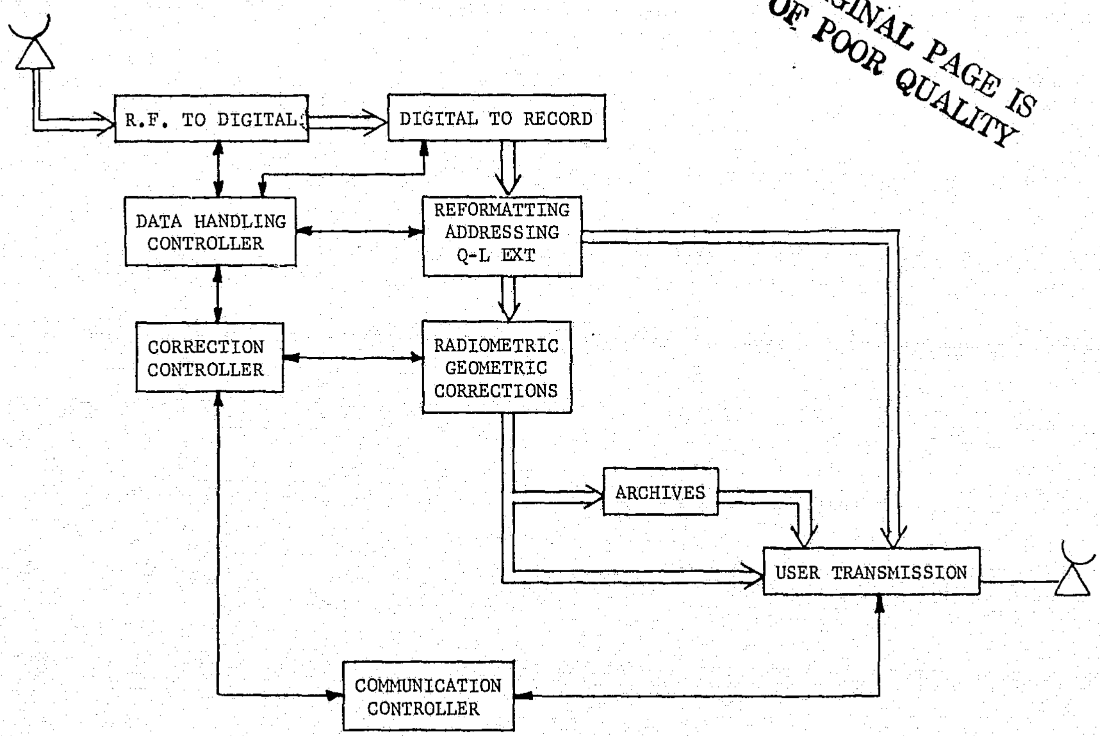


Figure 4-19. Baseline Central Facility (30m/7-Band)

4.11 New Technology Requirements

To implement the data-dissemination network, new technology developments are required, especially for the 10m/12-band case. The level of technology required is, in general, a function of either the rate at which raw data is pumped into the system or the preprocessing time required per pixel to keep up with the data flow. For the various areas of technology associated with earth-resources data collection and dissemination, Figure 4-20 estimates the points in the continuums of input data rate and preprocessing speed per pixel, respectively, above which new basic research funds (in contrast to current or minor extensions of current research funds) must be committed.

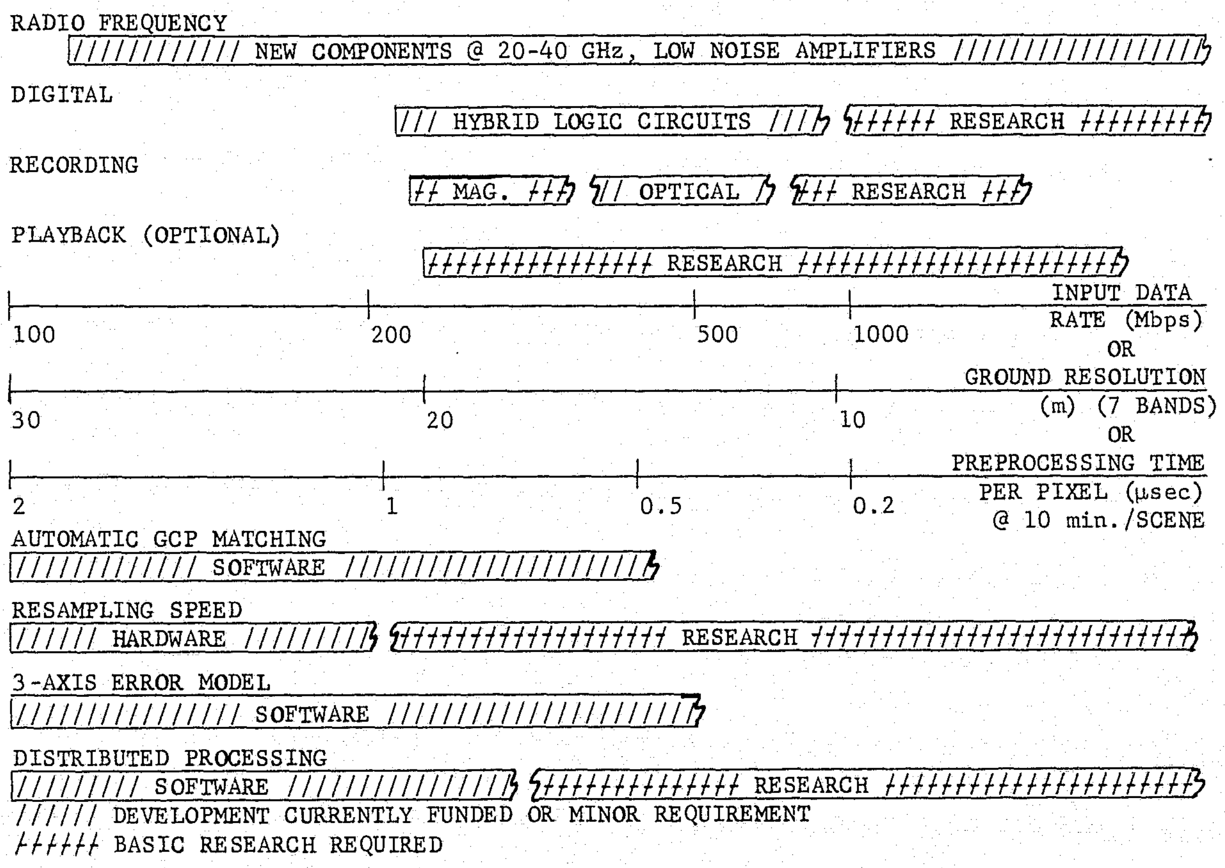


Figure 4-20. Technology Requirements

At a raw data rate of 120-Mbps or less, the 14-GHz band will suffice, and present-day RF and digital-component technology can be used. At higher rates, the ERS data transmission links must move to higher frequencies where RF technology is less developed. This is especially true at 40 GHz.

Existing technology is adequate to record the 30m/7-band data at 102 Mbps. Furthermore, current development projects such as the RCA High-Density Multitrack recorder will extend the recording capability to 240 Mbps. The most promising technique for higher rates appears

to be optical recording. Harris Radiation Inc. has demonstrated hologram recording on 35-mm film at 600 Mbps [7]. An extension of this technique to two 800-Mbps channels would permit recording of the 10m/12-band 1580-Mbps signal as received from a QPSK demodulator.

Developments in preprocessing technology include software development of automatic ground-control-point (GCP) matching, necessary to perform accurate data indexing and geometric correction. Current techniques are reliable only about 70% of the time. More accurate modeling of 3-axis satellite attitude variations (caused by solar pressure, for example) are necessary in performing geometric corrections more accurately. Finally, the development of distributed processing techniques is necessary to achieve higher throughput rates.

At present, IBM is developing a preprocessing system for NASA/GSFC capable of approximately 3.75 μs/pixel. The 30m/7-band LANDSAT-D system requires a speed of approximately 2 μs/pixel. The 10m/7-band system requires up to 0.15 μs/pixel. A considerable amount of research effort is required to achieve this reduced preprocessing time together with the greater accuracy required. This research effort will require outside support if it isn't being funded out of military intelligence budgets.

SECTION 5.0

CONCLUSIONS

The major conclusions from this study are as follows:

a. Data from satellites in sun-synchronous polar orbits (700-920 km) will generate most of the earth-resources data in the 1985-1995 time period.

b. Data from aircraft and Shuttle sorties, being either on film or tape, requires specialized processing and handling, and cannot be readily integrated in a data-dissemination network unless already preprocessed in a digitized form to a standard geometric coordinate system.

c. A potential demand now exists for earth-resources data delivered within 1-2 days after reception by a data readout station. The U. S. Department of Agriculture and the U.S. Department of Interior are major potential users of such data.

d. Data transmission between readout stations and central preprocessing facilities, and between preprocessing facilities and user facilities are most economically performed by domestic communication satellites. This is especially true for a 10m/12-band system. The satellite transponder channel is either leased, or a transponder may be placed on a geosynchronous earth-resources satellite. User earth terminals for data reception may be leased or owned by the user. An exception to the above is when a user requires a small amount of data (less than 1 scene of the 30m/7-band data)* and the distance is less than about 600 miles, in which case, common-carrier terrestrial links are more economical. Mail or courier service is most economical if timeliness is not critical.

e. Transmission of preprocessed data to the user by satellite is most economically accomplished by broadcasting all the data, scene-by-scene, suitably identified by address codes so that each user can automatically extract the data of interest.

f. Given that most users will receive their data via broadcast satellite, a single facility consisting of a centrally located readout station, preprocessing equipment, and data dissemination equipment is more economical than networks with distributed or separated facilities. This is true over a wide range of costs for the preprocessing equipment.

g. All data can be preprocessed and broadcast to the user within one day of reception from the earth-resources satellite provided a preprocessing time of 10 to 15 minutes per scene is achieved and is coupled with a communication satellite link capacity of 6 Mbps for the 30m/7-band case, and 120 Mbps for the 10m/12-band case.

h. Real-time user interaction with the data dissemination network is feasible provided the interaction is based on quick-look data, i.e., unpreprocessed data. In light of

* 1 scene (all bands) of 30m/7-band data is less than 1/15th scene (all bands) of 10m/12-band data.

conclusion (g), a substantial volume of data from quick-look requests is not foreseen. Furthermore, the impact of user interaction on the total system cost is small.

i. Use of TDRS is not cost effective for continental-USA coverage, unless the cost of TDRS is less than $100K/year. However, if the data dissemination network is expanded to cover areas outside of the North American continent, then TDRS probably becomes more economical than the implementation and operation of additional readout stations. TDRS has insufficient capacity for the 10m/12-band system.

j. The addition of Alaska (including its continental shelf) to the lower-48 states increases the total data volume by 50% and the annual cost of implementing and operating the data-dissemination network by approximately 35%.

k. The implementation of a LANDSAT-D type system (30-meter resolution with 7 spectral bands) is technically feasible and within today's state-of-the-art.

l. The implementation of a 10-meter resolution system with 12 spectral bands requires a considerable advance in the state-of-the-art, especially in the development of high-frequency (20-40 GHz) high-data-rate (1.58 Gbps) technology, and accurate (10 meter) high-speed (0.15 μs per pixel, or 10 minutes per scene) geometric correction technology.

m. From an overall cost standpoint, the use of data compression equipment in disseminating 30m/7-band data does not seem justified. Use of data compression may be justified in a 10m/12-band system.

n. A direct readout link for a 30m/7-band system will require a 100-MHz channel bandwidth allocation. A carrier frequency of 14.45 GHz is recommended. For a 10m/12-band system, a channel allocation of at least 1 GHz is required. The 20.2-21.2-GHz band is recommended. An alternative is the 40-41-GHz band.

SECTION 6.0

RECOMMENDATIONS

With the methodology and computer simulation program developed under this contract, a number of additional studies could be performed:

a. Examine effect of cloud cover on system performance, required parameters, and cost. A statistical model would be developed which would be incorporated in the simulation program.

b. Examine impact of expanded coverage, including Hawaii, and international areas.

c. Define and simulate the function of the area center. Expand to include user unique processing and user interaction.

d. Optimize the network parameters for other user demand models, emphasizing multi-discipline missions (e.g., SeaSat, StormSat, SEOS, etc.).

e. Examine impact on user costs of various strategies for allocating network operation costs (e.g., pricing strategies).

The use of earth-resources data is still in its early stages of development. It is expected that both user requirements and applicable technology state-of-the-art will change significantly over the next few years. Such changes should be taken into consideration when interpreting the results of this study in the future.

REFERENCES

1. Private Communication with John Sos, Goddard Space Flight Center.

2. Private Communication with Dr. Thomas Lynch, Goddard Space Flight Center.

3. "User Data Dissemination Concepts for Earth Resources," Final Report, Contract No. NAS2-8964, Aeronutronic Ford Technical Report WDL-TR7187; June 1976.

4. Private Communication with Don Zoller, EROS Data Center.

5. Kittiver, C., and Zitzmann, F. R., "The SBS System - An Innovative Domestic Satellite System for Private-Line Networks," AIAA/CASI 6th Communications Systems Conference, April 5, 1976, AIAA/CASI Paper 76-307.

6. Watkins, Al, "The Role of the EROS Data Center within the Earth Resources Program," presented at Earth Resources Survey Symposium; June 1975.

7. Private Communication with Thomas Healey, Harris Radiation, Inc.